

California Climate Change Scenarios Assessment

Dan Cayan Scripps/UCSan Diego, USGS

With

Noah Knowles USGS

Mike Dettinger USGS

Mary Tyree, SIO/UCSD

Amy Luers (UCS)

Alan Sanstad (LBNL)

Guido Franco (PIER/CEC)

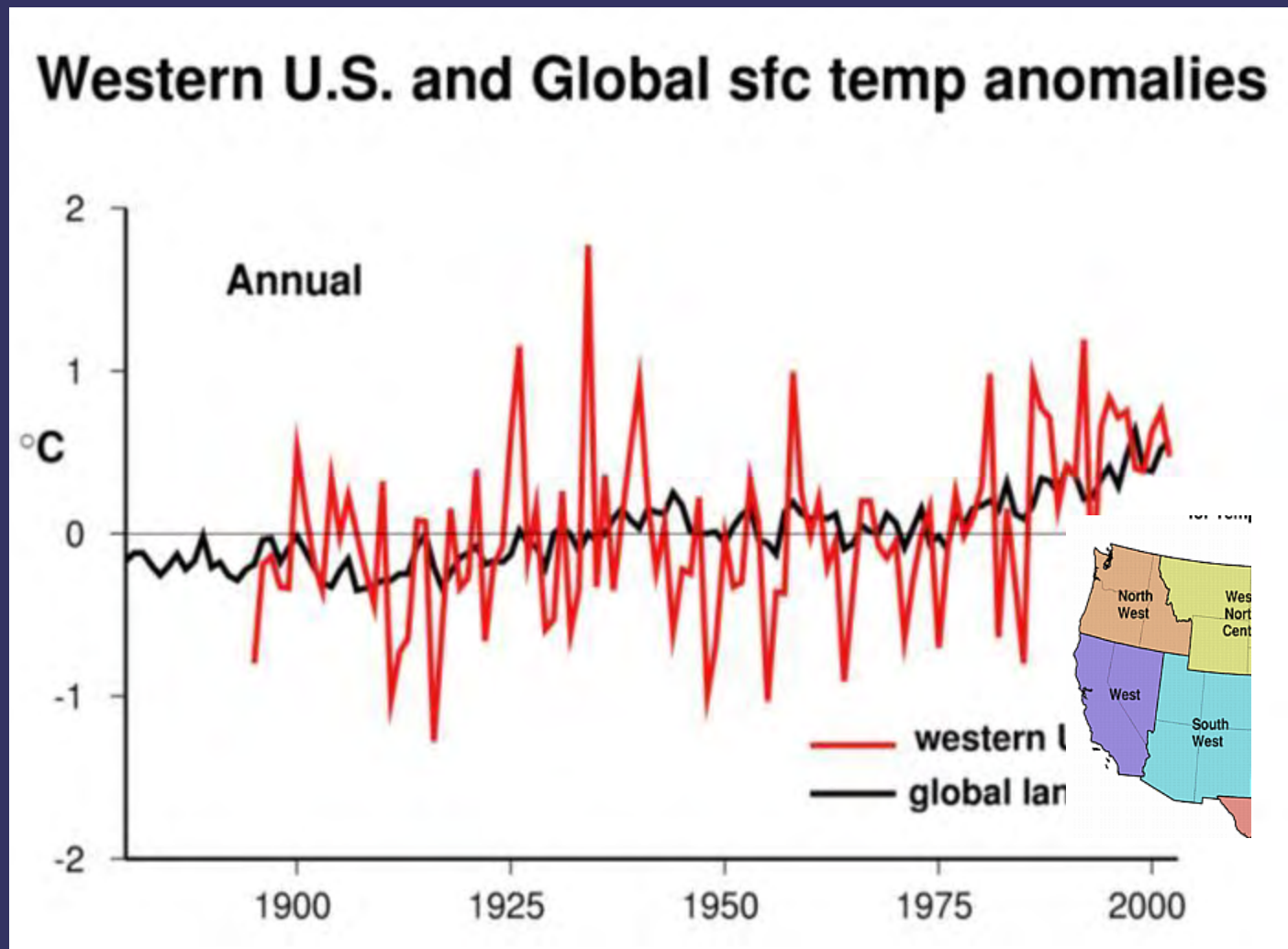
California Climate Change Scenarios Project

Background Information

- June 1, 2005 Executive Order S-3-05 by California Governor S that mandated preparation of biennial scientific assessments on potential impacts and adaptation options
- 2006 legislation [Assembly Bill 32](#) to reduce GHG emissions to 1990 levels by 2020 - a reduction of about 25 percent, and then an 80 percent reduction below 1990 levels by 2050.

Climate Scenarios Goal:
*bring climate science to policy
makers and managers*

During recent history, temperature changes in west U.S. have tracked those in global temperature



Global land data from the Global Historical Climatology Network (GHCN; Version 2) and global SST data from the UK MOHSST and NCEP OI SST (Version 2) anoms based on 1880-2002 mean

Western U.S. data from the time bias corrected NCDC statewide-regional-national dataset (Climate Division data) anoms based on 1895-2002 mean

Annual Surface Temperature Change



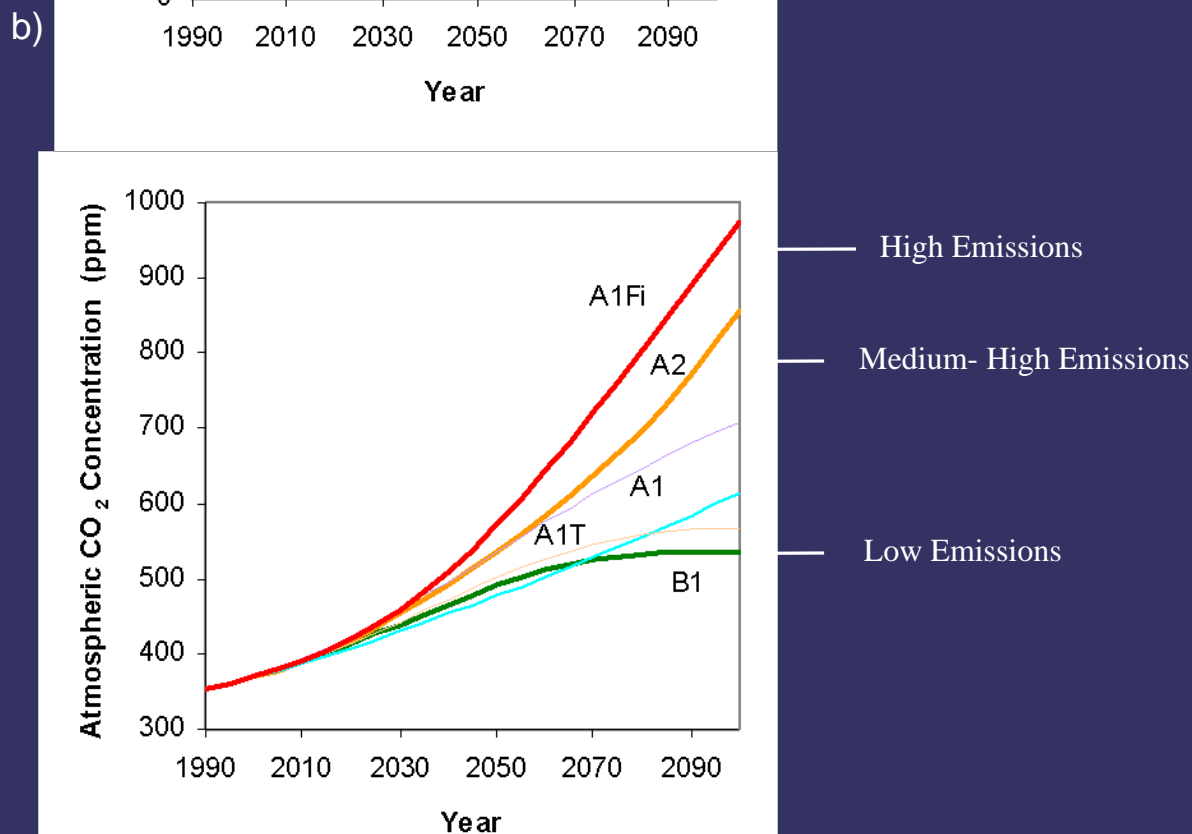
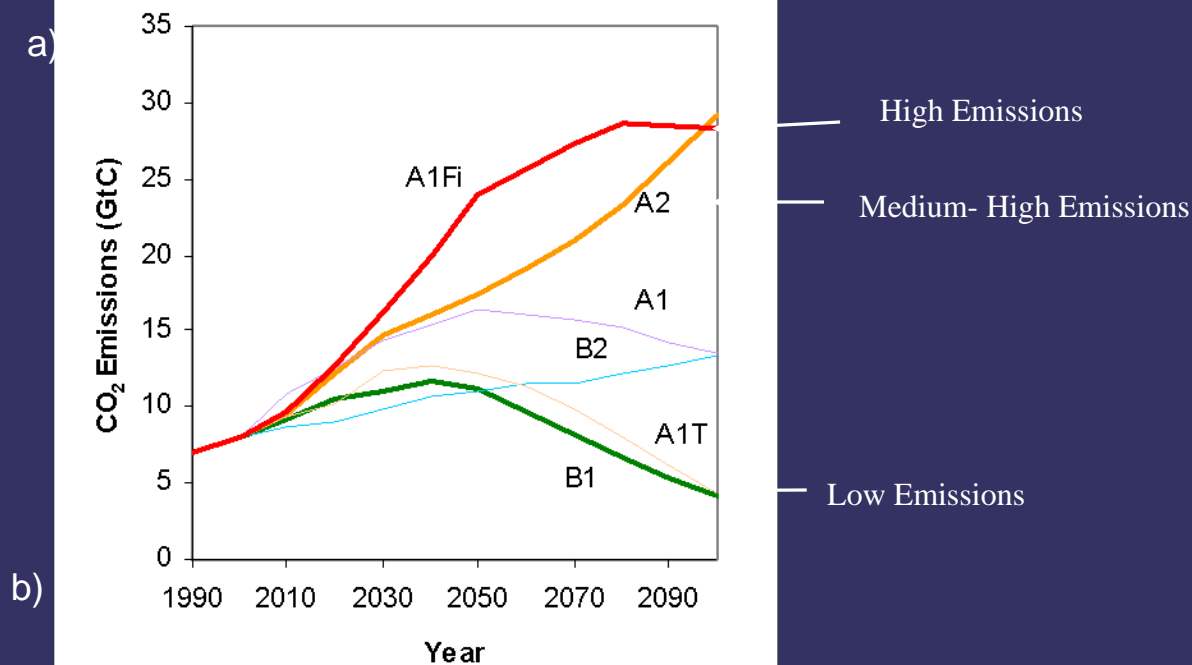
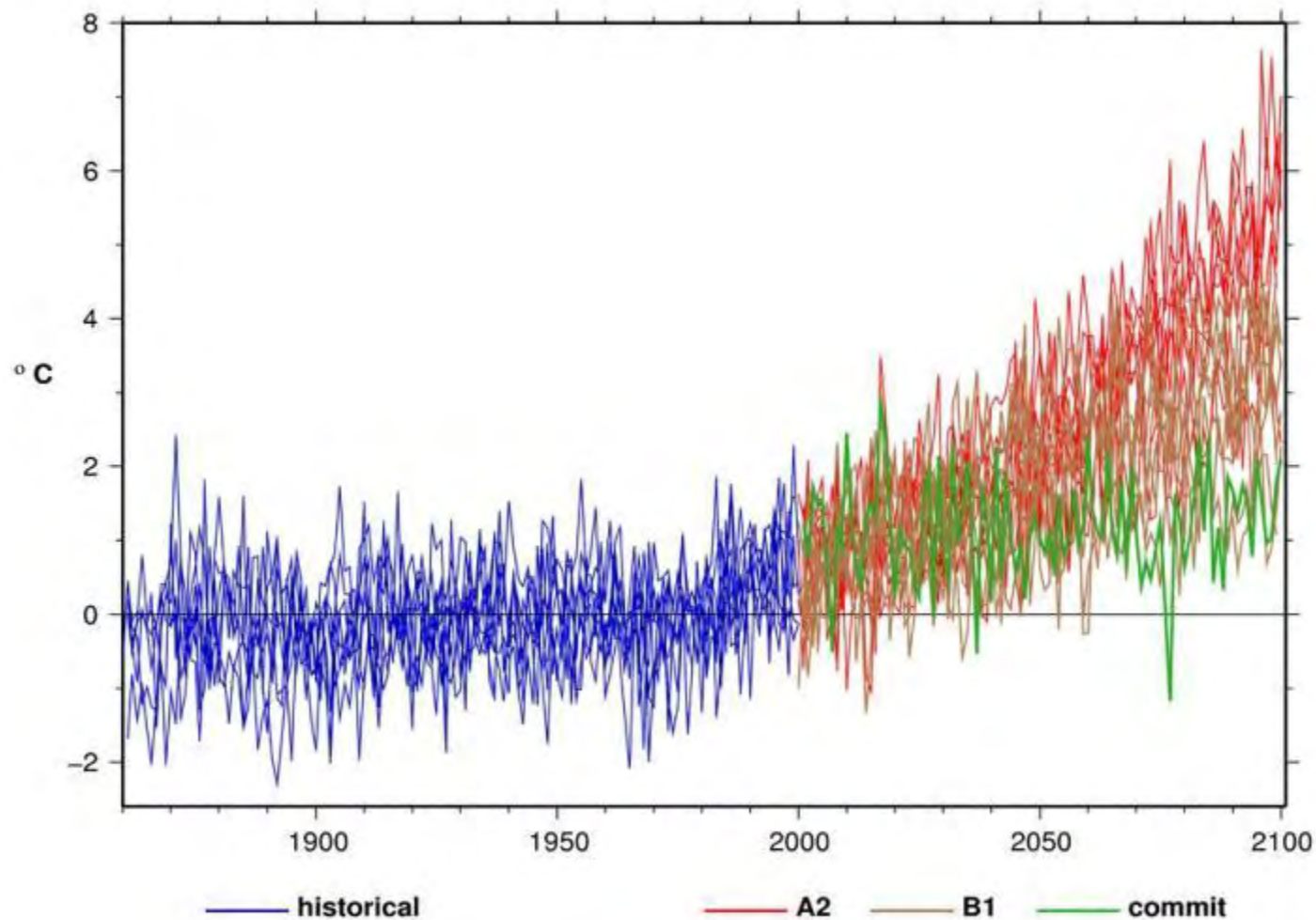


Figure 1. IPCC SRES Emission Scenarios (Nakicenovic, N. et al., 2000). The trajectories in Figure 1 do not exactly match those in official IPCC documents because the results we report here are based on revised emissions projections subsequently made available by IPCC; these are available at <http://sres.ciesin.columbia.edu/>. In addition, the authors used a new version of MAGICC available from <http://www.cgd.ucar.edu/cas/wigley/magicc/index.html>. The differences between Figure 1 and similar figures provided by the IPCC, however, are minor and do not affect the discussion in this paper.

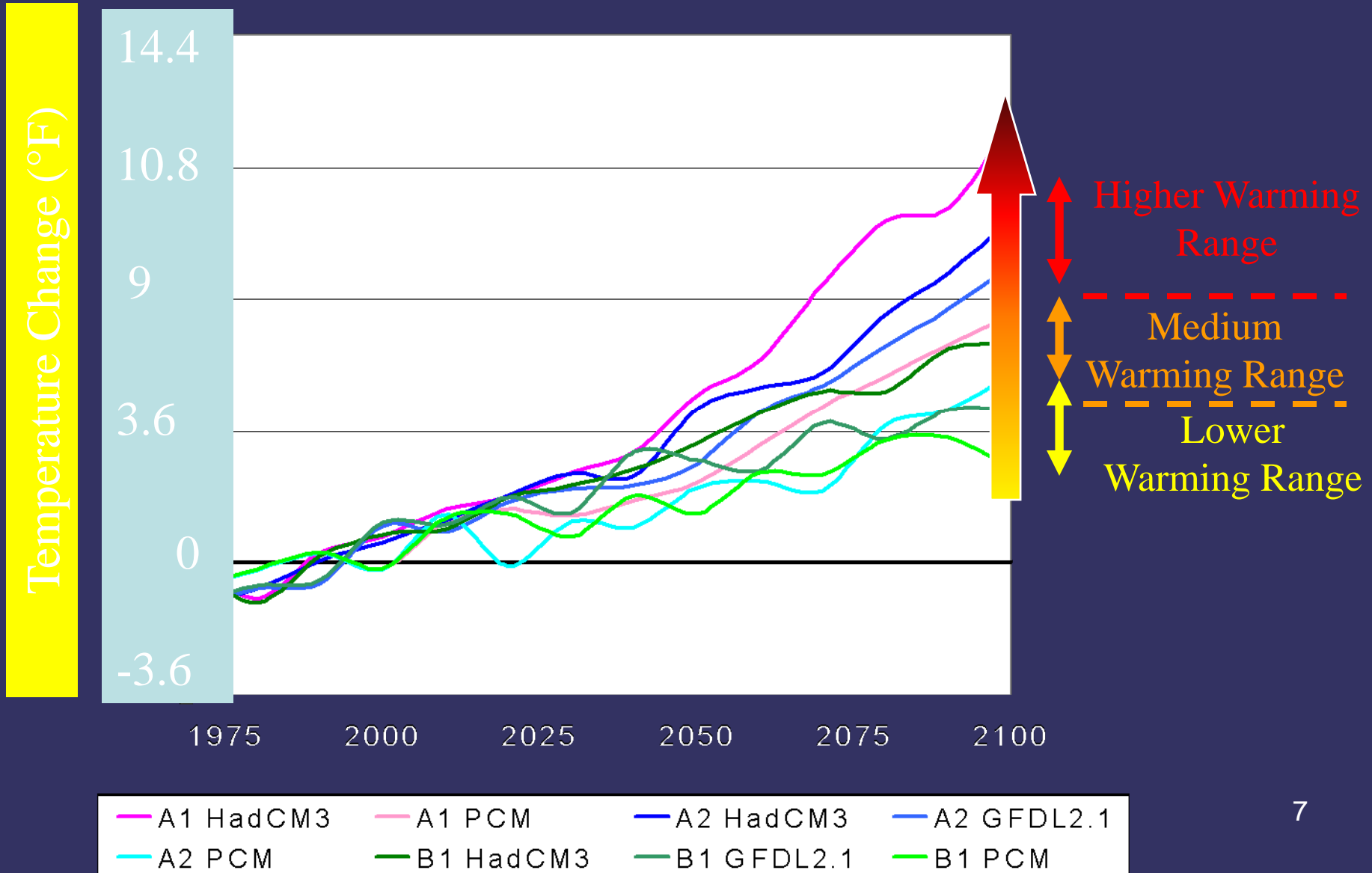
Annual Temperature Projections, Sacramento area
from 8 IPCC AR4 global climate models, SRES A2, B1 and commit



GFDL CM2.1 --- NCAR PCM1 --- MIROC3.2 --- CSIRO Mk3.0
IPSL CM4.0 --- MPI ECHAM5 --- CNRM CM3.0 --- UKMO HadCM3

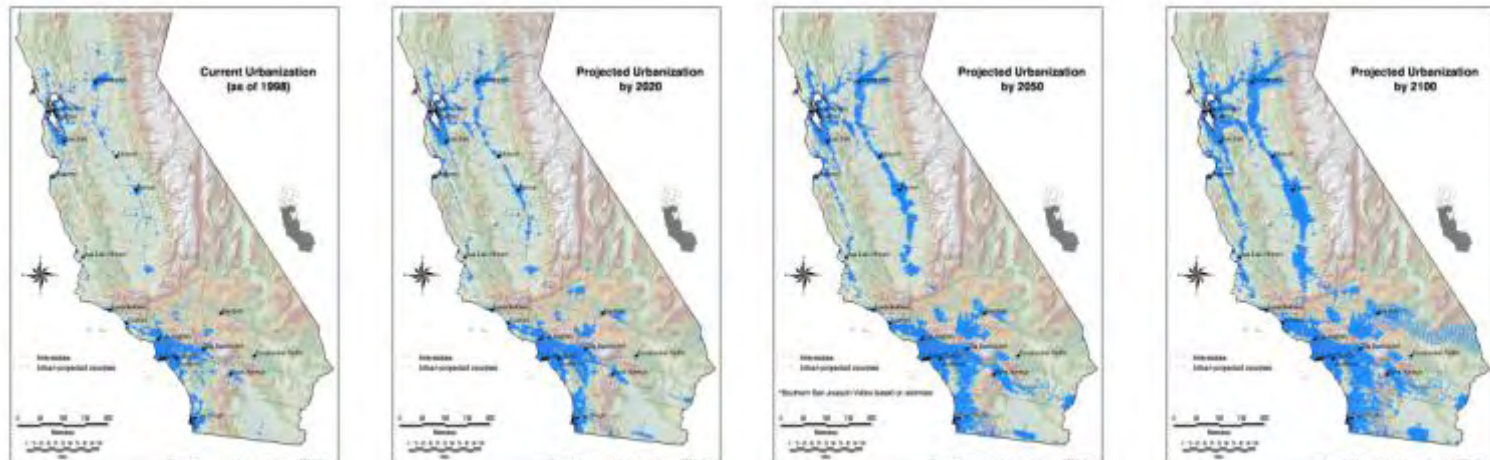
Uncertainty: Projected Warming Ranges

Statewide annual average (°F)



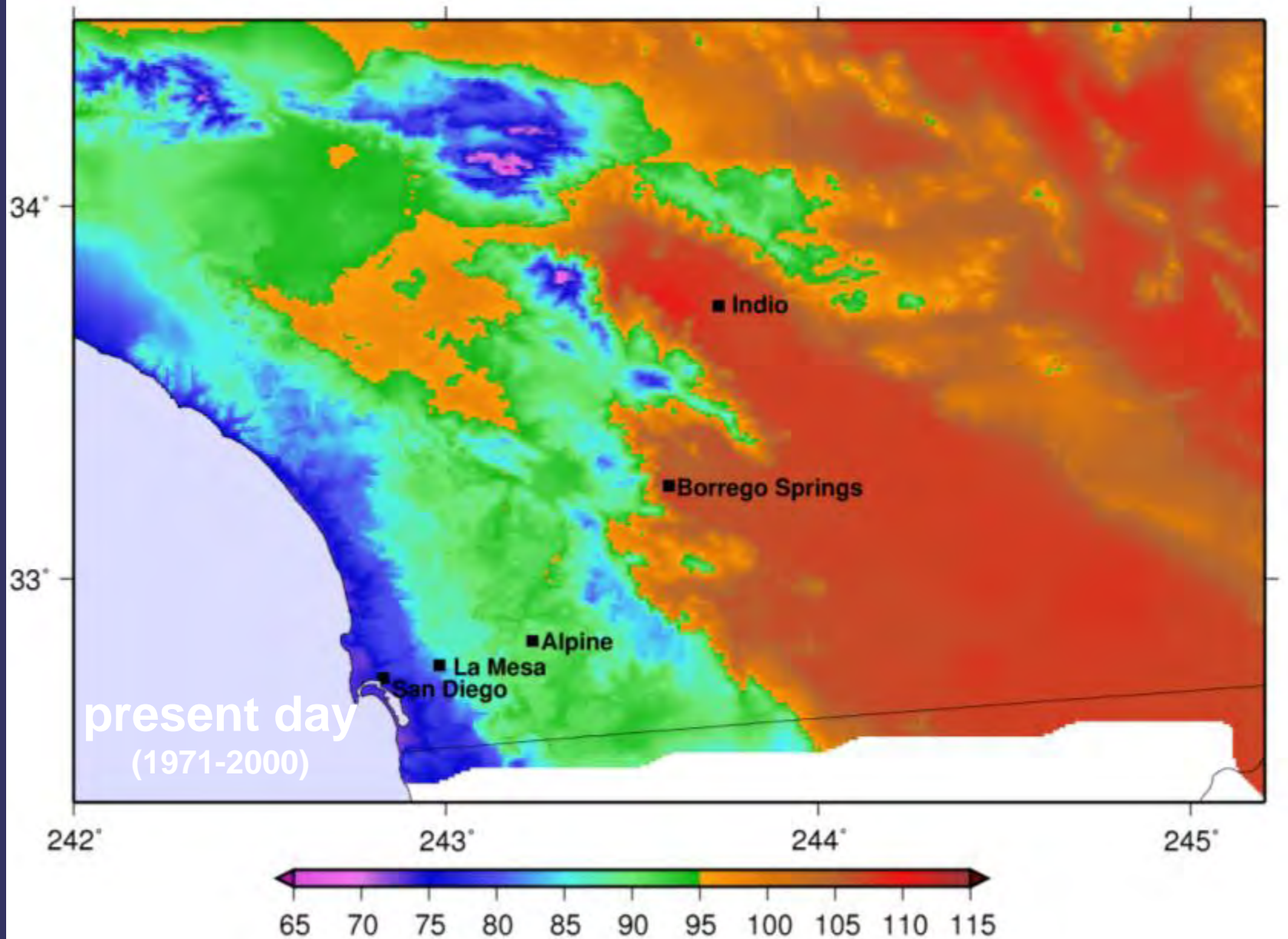
Demographic and urban projections

- PPIC will develop the demographic projections (SRES scenarios)
- LLNL will develop the urban projections



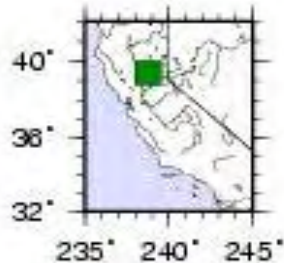
Landis et al. 2003
PIER Report

July average daily maximum temperature

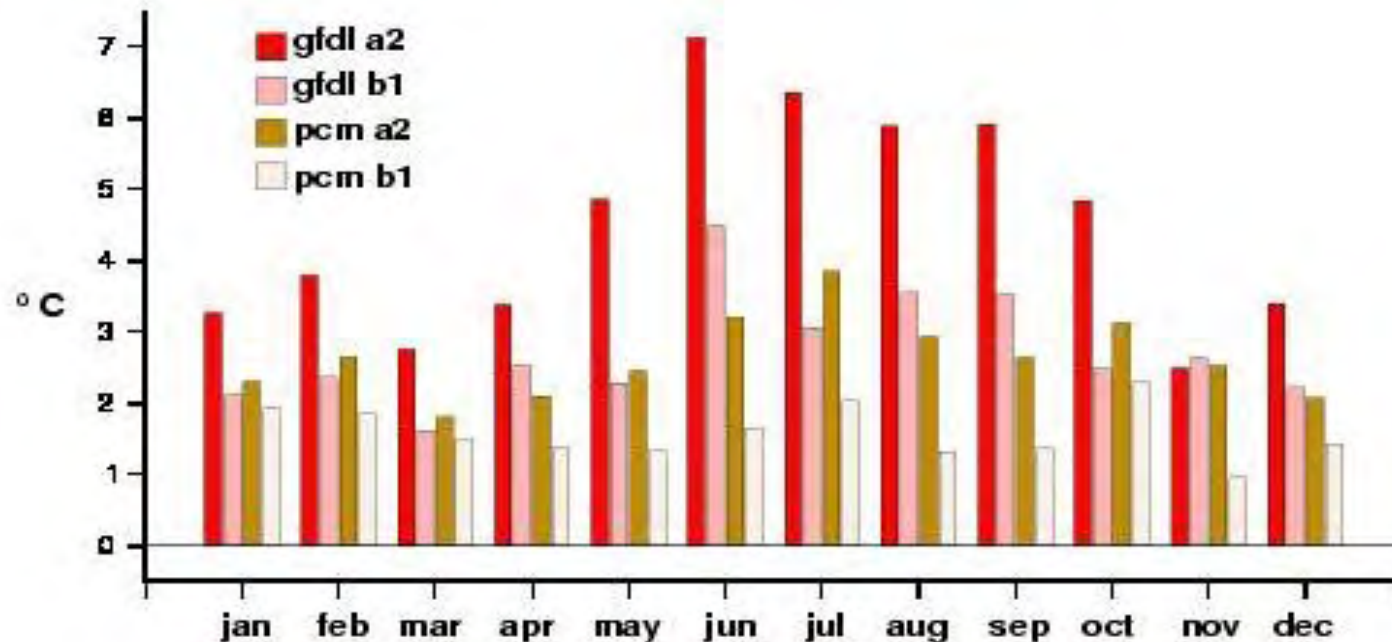


Seasonally intensified warming?

some models suggest amplified summer warming

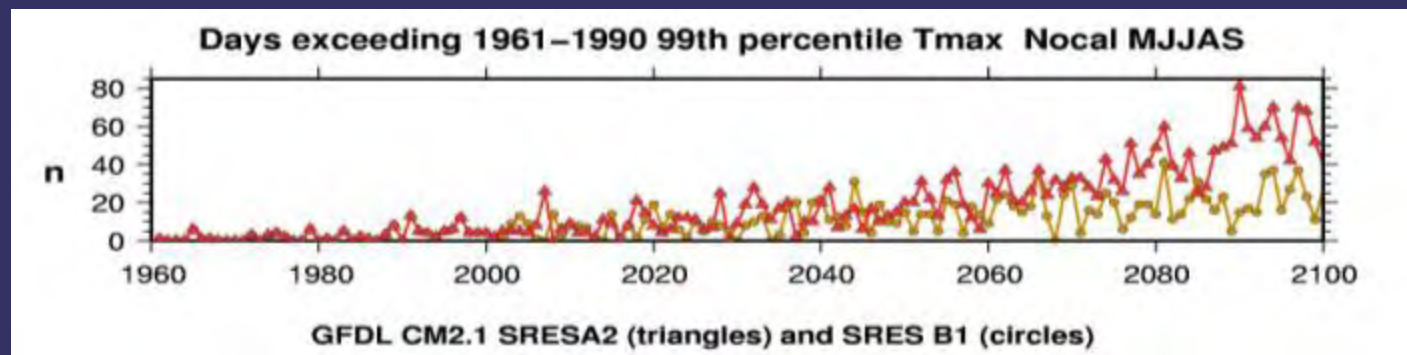
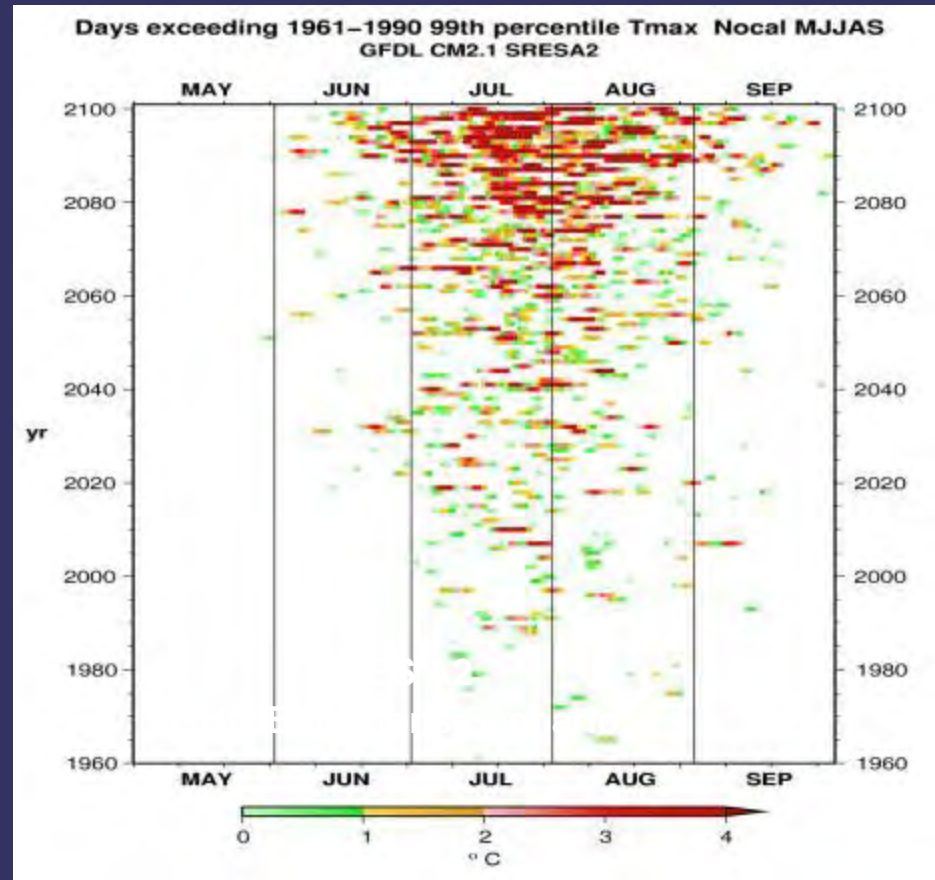


Nocal temperature anomaly
2070–2099 minus 1970–1999



need to understand event scale phenomena

projected heat wave days

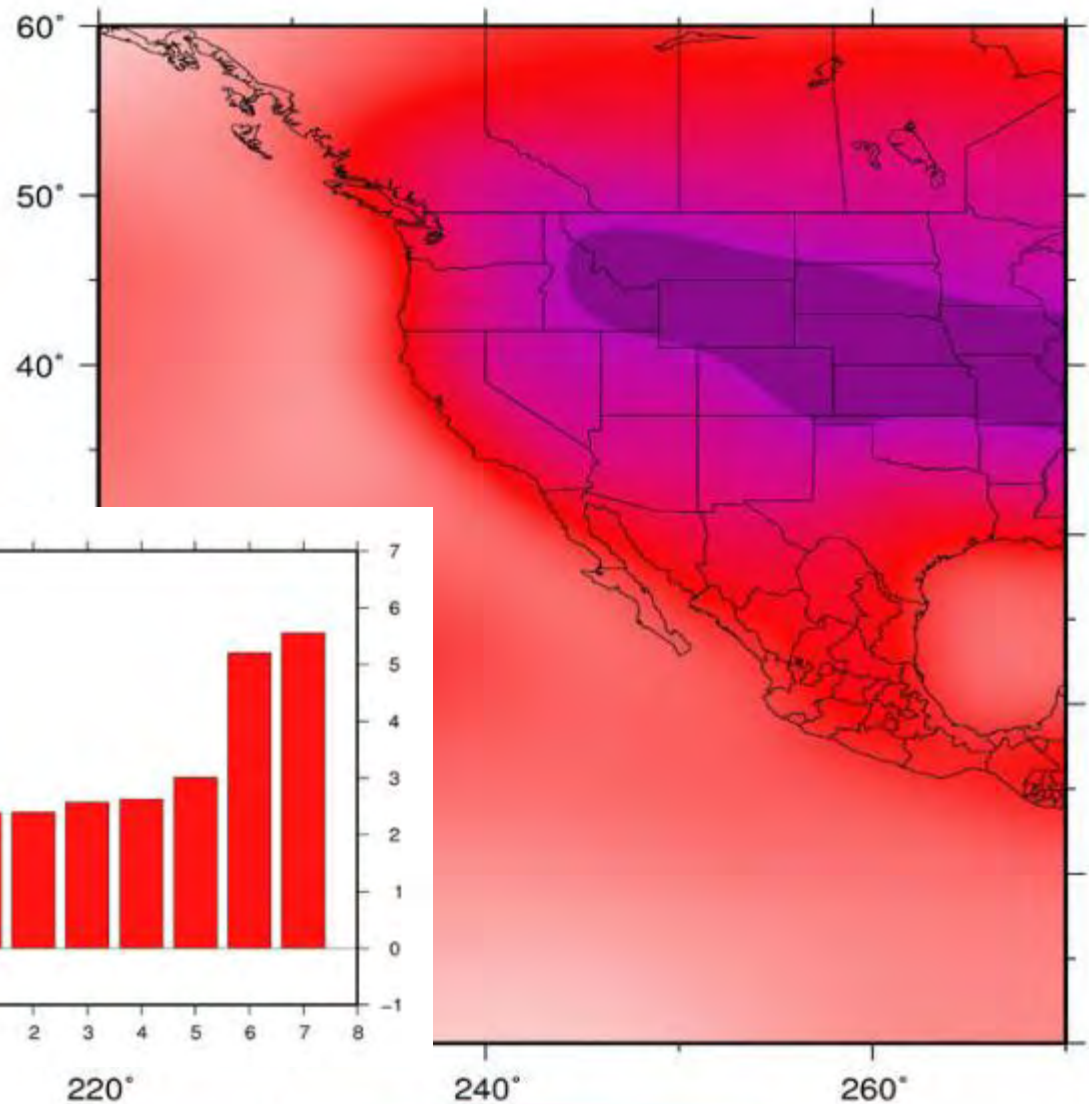


*Climate models project
1.5-2.0°C ocean surface warming
by end-of-century.*

*Greater warming on land
than oceans would amplify
California coast-interior thermal
gradient.*

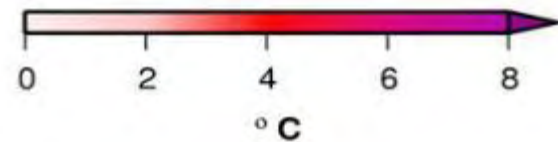
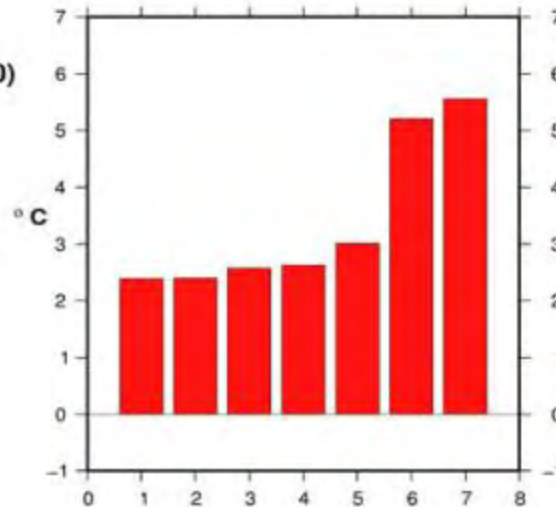
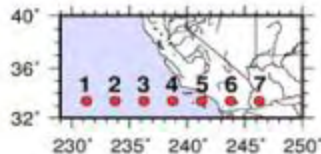
*Summer land warming
is accentuated*

GFDL CM2.1 Jun-Aug air temp change
2070-2099 minus 1961-1990



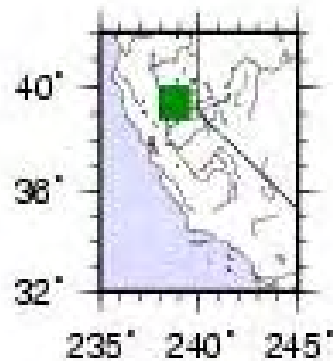
**sfc air temp difference
(2070-2099 minus 1961-1990)
sresa2 gfdl cm2.1
jja**

southern calif transect

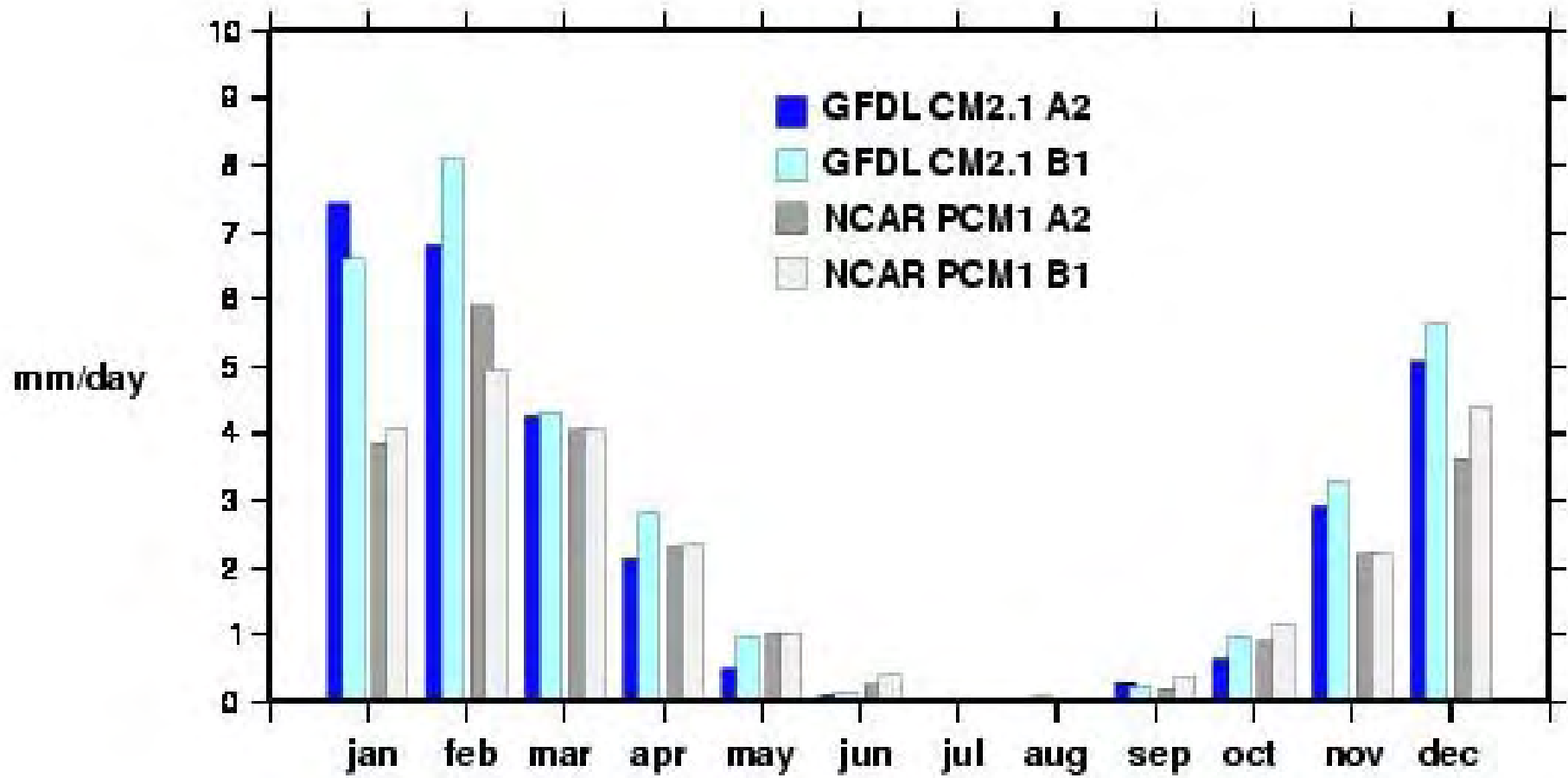


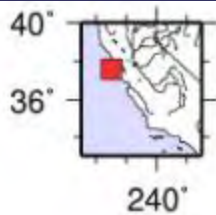
*GFDL CM2.1 is a medium-high
sensitivity model. Other models
produce less (or more) warming*

Mediterranean precipitation regime remains



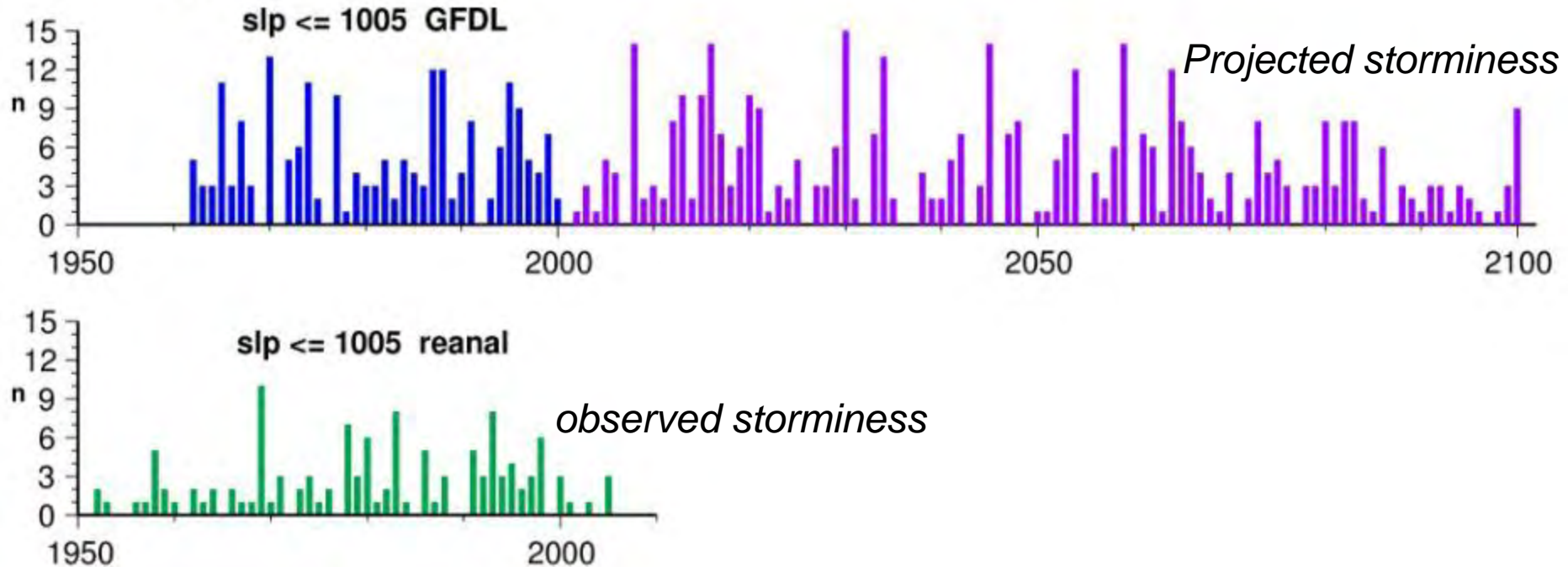
Nocal precipitation
climate projection 2070–2099





San Francisco daily storm counts Nov-Mar

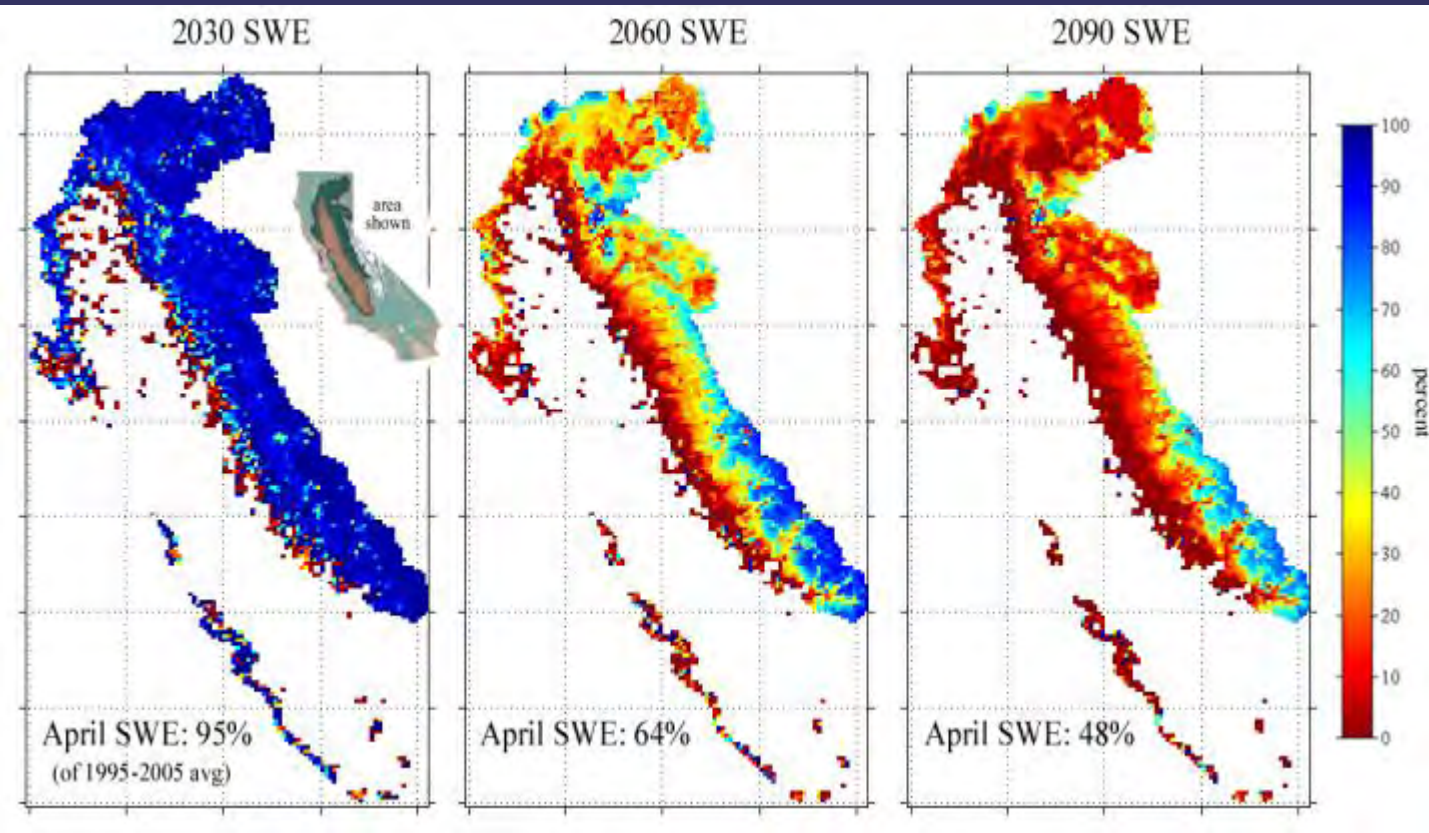
GFDL historical (20C3M), SRES A2 projections and Reanalysis observations



Storminess projected by climate models
remains consistent with historical levels.

Number of days per year of events with SLP is 1005 hPa or lower in vicinity of San Francisco from GFDL A2 simulation 1962-2100 (upper), and from NCEP/NCAR Reanalysis 1950-2004 (lower).

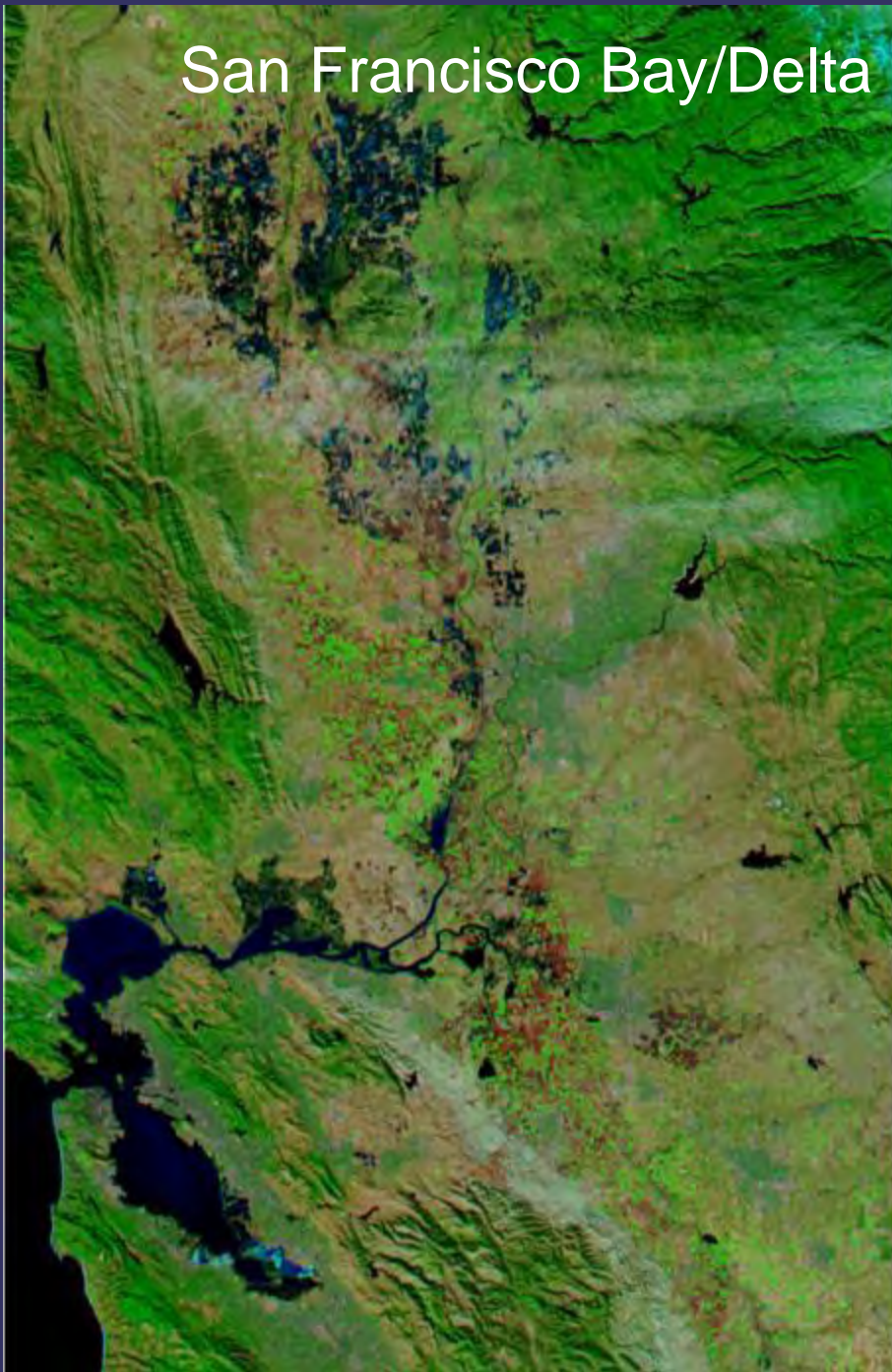
We face significant losses of spring snowpack



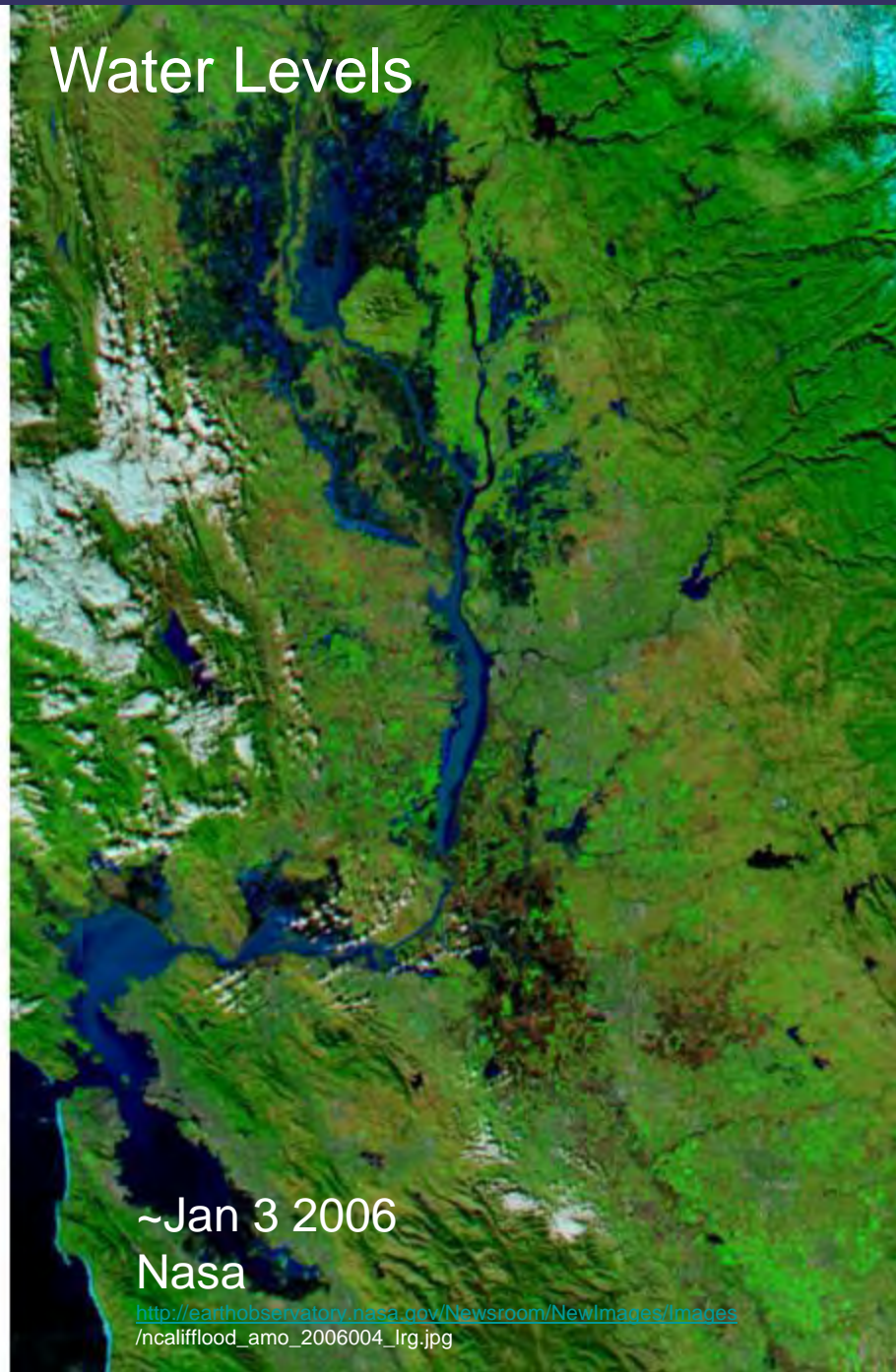
- Less snow, more rain
- Particularly at lower elevations
- Earlier run-off
- More floods
- Less stored water

By the end of the century California could lose half of its late spring snow pack due to climate warming. This simulation by Noah Knowles is guided by temperature changes from PCM's Business-as-usual climate simulation. (a middle of the road emissions scenario)

San Francisco Bay/Delta



Water Levels



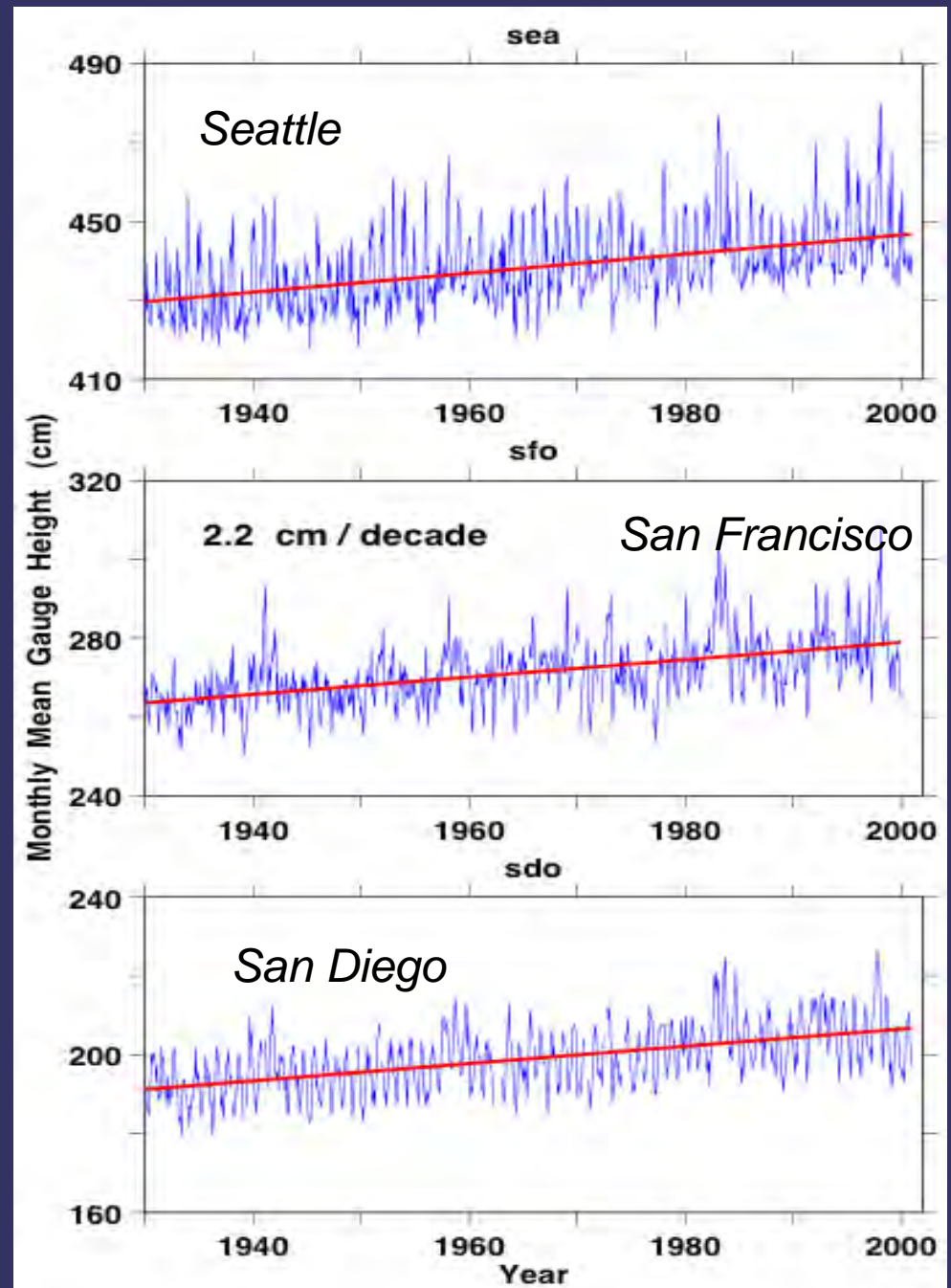
~Jan 3 2006

Nasa

http://earthobservatory.nasa.gov/Newsroom/NewImages/Images/ncalifflood_amo_2006004_lrg.jpg

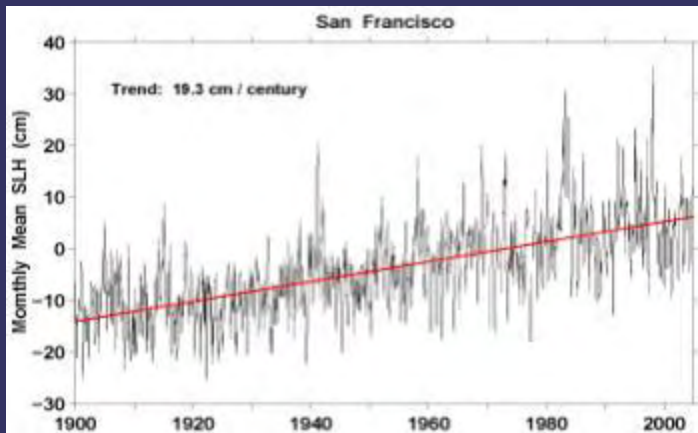
Historical tide gage observations of mean sea level at San Francisco, Seattle and San Diego exhibit secular increase of ~2cm/decade

This is consistent with estimates of global sea level rise

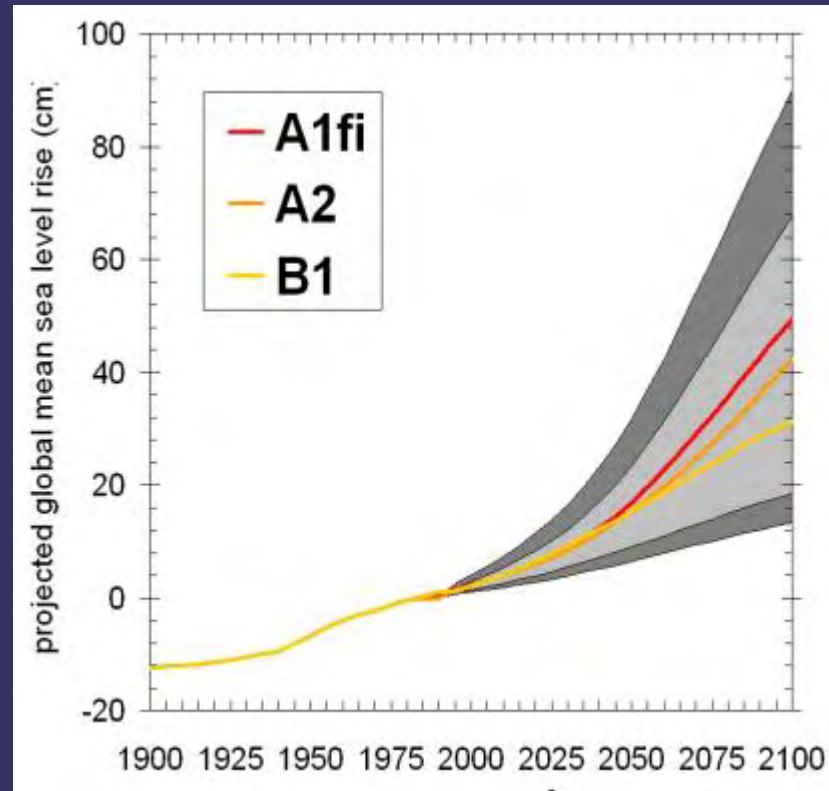


Observed SFO (left) and modeled Global (right). Sea level rise estimates based upon an envelope of output from several GHG emission scenarios

observed



Projected envelope of global s.l. rise



Climate models

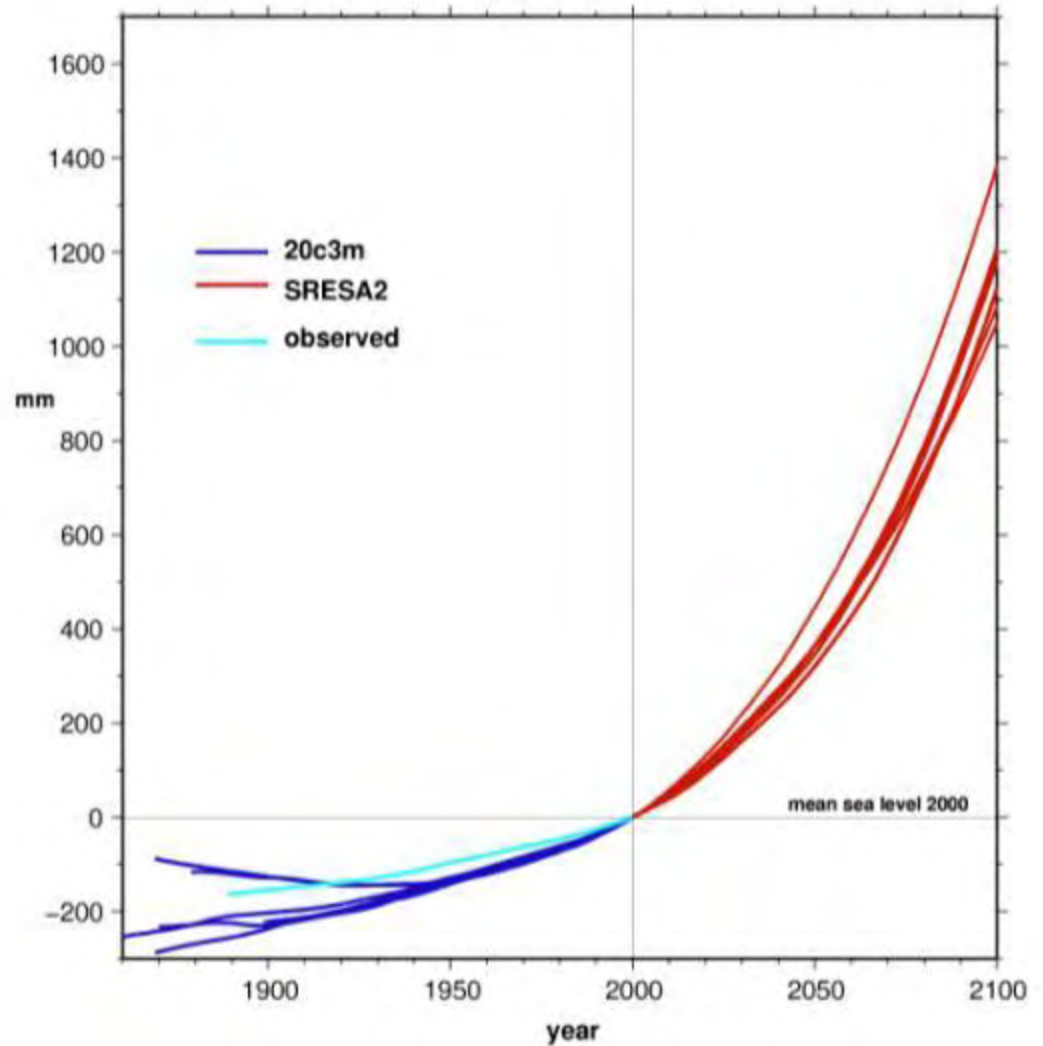
Only provide loose guidance on

The amount of sea level rise, but

It is very likely that rates will increase

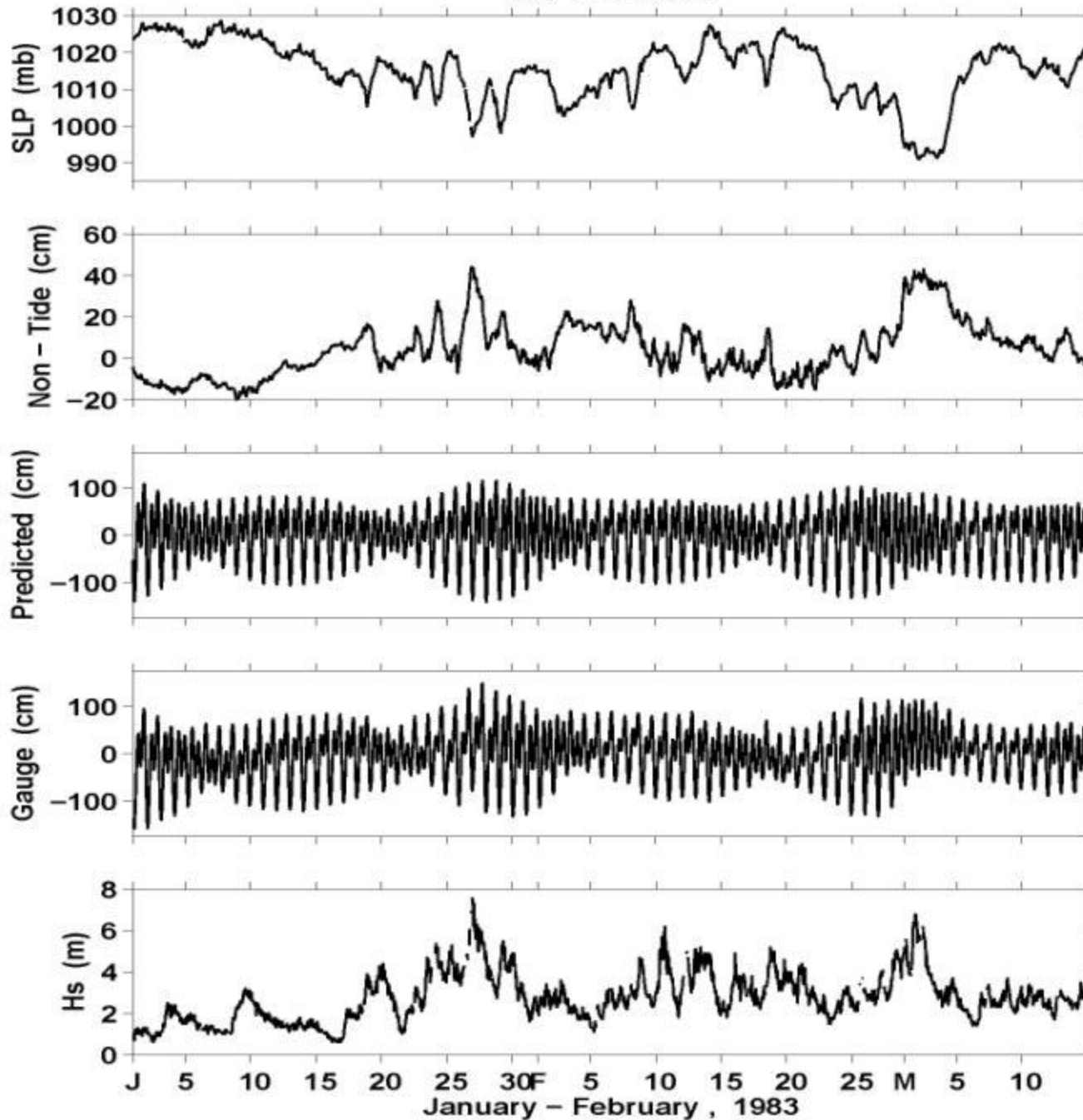
Global sea level projections

adjusted for effects of dams



CNRM CM3 — GFDL CM2.1 — MIROC3.2 (med)
MPI ECHAM5 — NCAR CCSM3 — NCAR PCM1

San Francisco



Sea level pressure

Sea level, tide-removed

Sea level, tide prediction

Sea level, observed

Wave Height

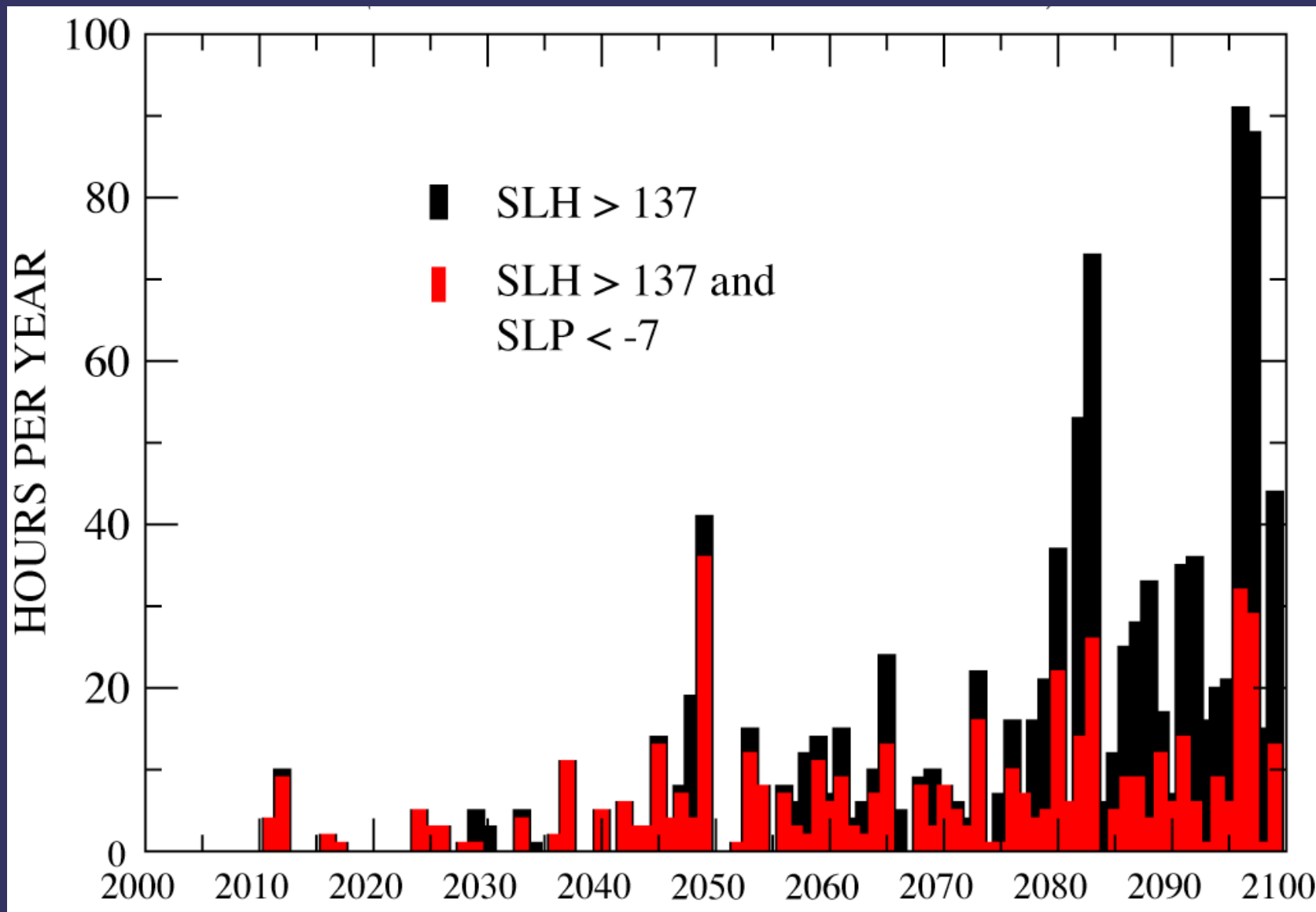


Figure 5. Projected total exceedences of San Francisco hourly sea level height (SLH) above historical 99.99 percentile (black), and number that are coincident with sea level pressure anomalies less than -7mb. Projected sea level from GFDL model weather and Nino3.4 SST with a linear trend of 30cm over 2000-2100. (Cayan et al. In Review)

Next Steps

- Use hydrodynamic models to simulate 100 years of projected future tides for selected climate scenarios
- Refine estimates of local mean sea level and signal attenuation in channels around Bay and in Delta
- Include effects of storm and El Niño surges and river inflows on water levels
- Include levee height data and examine extreme events to assess overtopping potential
- Publish in peer-reviewed journal and make results available through Google Earth & Map

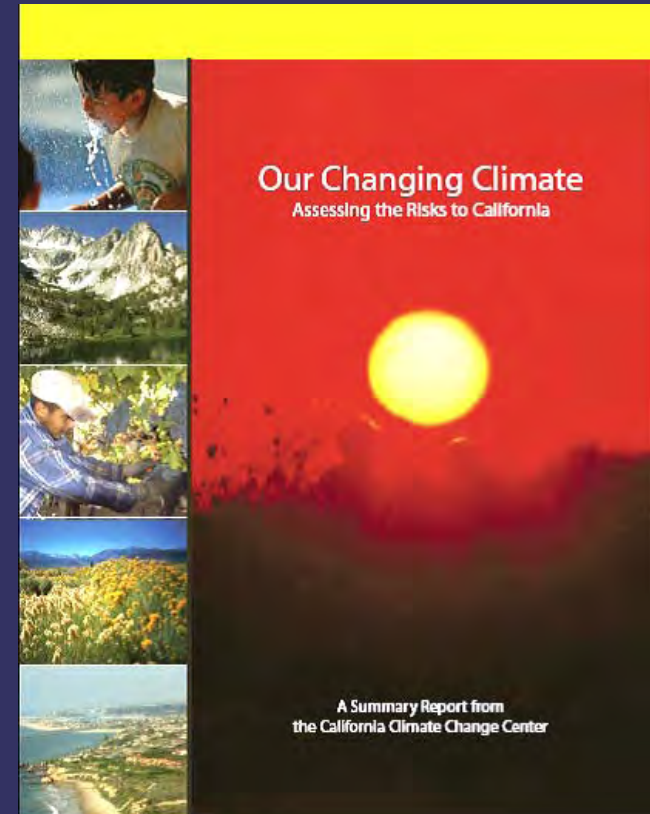
Thanks to Tom Coons for his work on the elevation dataset. Thanks also to the following who provided essential data: Joel Dudas, Bruce Jaffe, Amy Foxgrover, Theresa Fregosa, Cathy Ruhl, Brad Tom, Chris Enright, Bill Dietrich, Ionut Iordache, Tim Doherty, Jeff Mount, Ray McDowell

Funded by through the California Energy Commission's Public Interest Energy Research Program (PIER) through the California Climate Change Center at Scripps Institution of Oceanography, and the CALFED Science Program via the CASCaDE Project.

2006 Synthesis Scenarios Report: Message to Public

- By comparing impacts under multiple climate change scenarios were able to highlight for the public that:

The consequences of climate in action are high in CA



2006 Synthesis Scenarios Report: Message to Scientific Community

**20 papers from assessment
are in press in a special
issue of
Climatic Change**



2008 Scenarios Assessment

- Common set of climate and sea level scenarios
- Common set of demographic and urban projections intended to be consistent with the SRES scenarios
- Cover seven sectors:
 - Water resources, forests, agriculture, coasts, energy, air quality/Public health
 - Cross-sector studies
- How the 2008 study will differ from the 2006 study:
 - Economics
 - More Adaptation
 - Incorporating People

OBSERVATIONS AND MODELS INDICATE:

Humans have altered atmospheric composition and thus are altering the earth's climate; GH gases have long lifetimes, so choices made now and in future will greatly impact future climate.

Warming is already underway and more to come +2 to +5°F by 2050

Recent model projections suggest warming may be intensified in summer, especially in interior areas.

Recent IPCC model projections for western precipitation are scattered, but *several* show moderate drying as tends to be characteristic of Mediterranean regions globally.

Warmer winter storms would produce more rain, less snow, earlier flows, more floods. "Shoulders" of watersheds at 6000-8000' would generate more immediate runoff. This would compound sea level rise problem in Bay/Delta

Sea levels globally and along California coast will very likely increase its rate of rise. Rates are uncertain, but present range could result in moderate (1.5 ft) to large 4+ft rise in msl by end of century.

Frank Gehrke,
California Cooperative Snow Surveys, DWR

OBSERVATIONS AND MODELS INDICATE:

**Western Ecosystems are vulnerable to climate change--
snow hydro-climate changes across elevational gradients,
heightened wildfire risks.**

**Models predict greater warming in summer than in winter and
higher rates of warming at increased elevations.**

**In the future, floods may be intensified as larger proportions
of mountain catchments are likely to produce rainfall runoff
instead of snowpack**

Reduced spring snowpack is likely, and in proportion to climate warming

**Climate monitoring is imperative to track changes in the midst of
variability and to inform better decisions**

Projecting Vulnerability to Inundation due to Sea Level Rise in the San Francisco Bay and Delta

Noah Knowles, USGS Menlo Park

Projected sea level rise over the next century will affect the shoreline of the Bay/Delta, newly inundating some areas and increasing the risk of levee failure in others.

New elevation datasets make possible more accurate assessments of vulnerability than previously available.

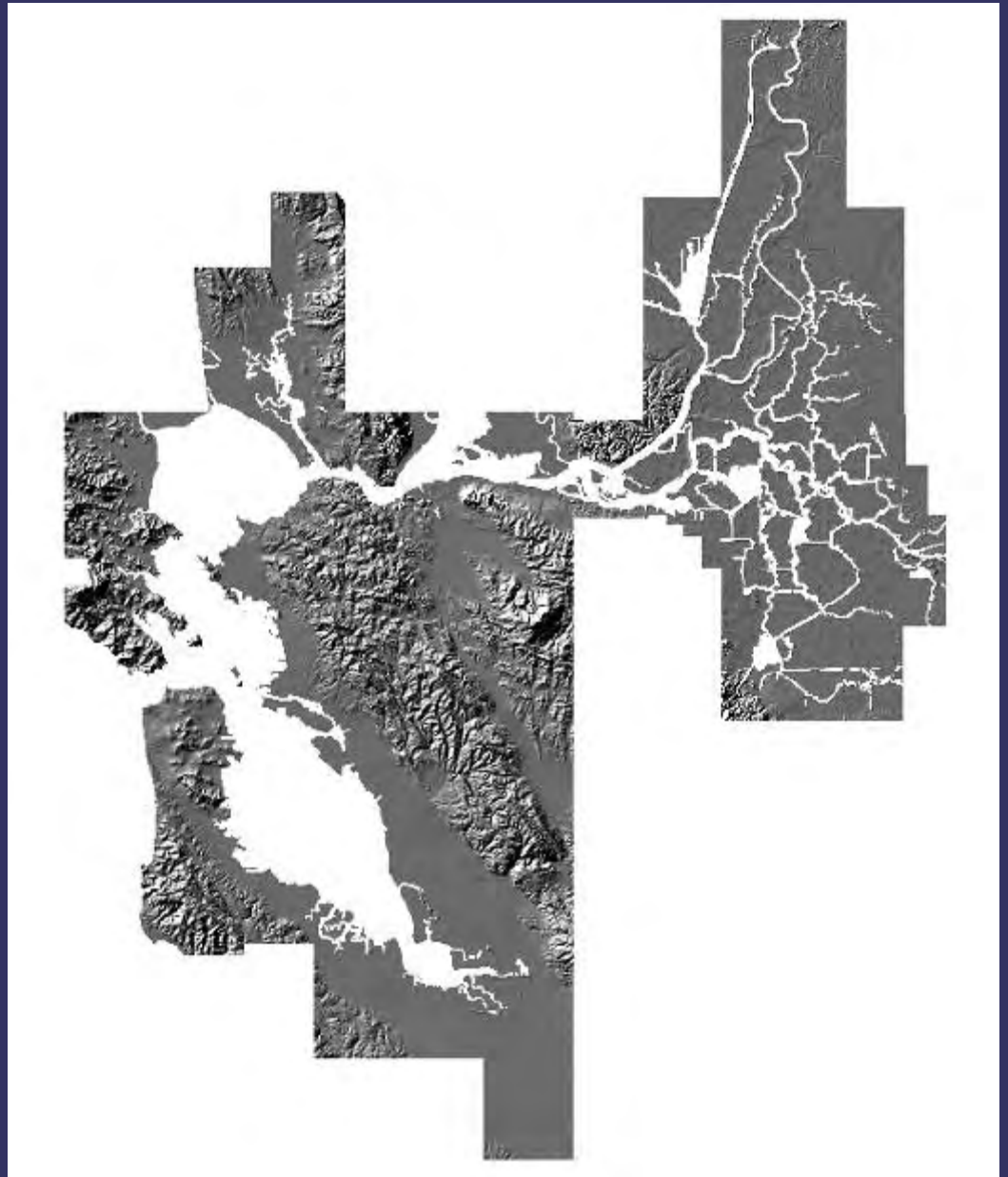
The present analysis shows areas at risk of inundation based purely on the elevation data. The effect of levees is, for now, ignored.

All results should be considered preliminary.

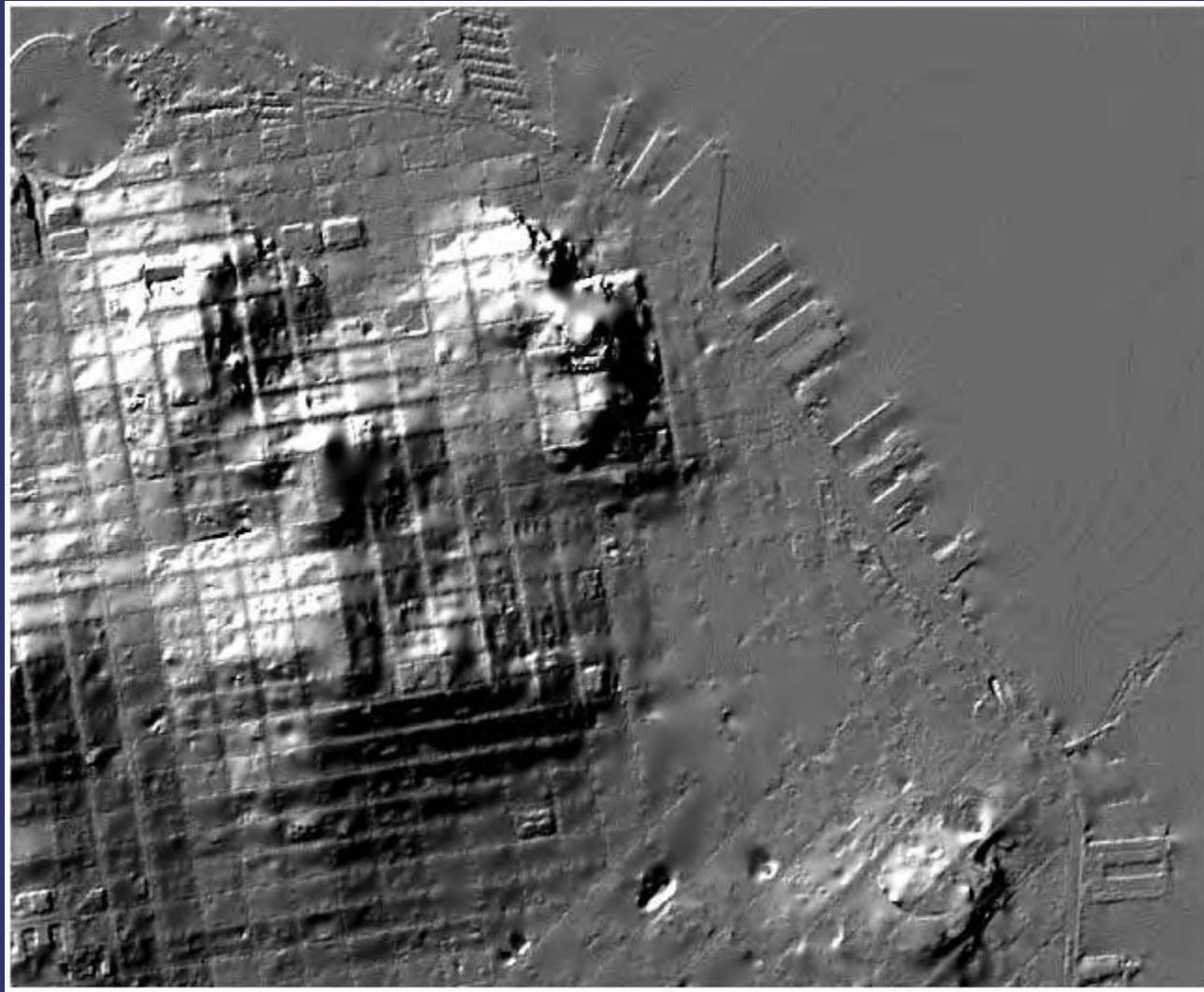
Funded by through the California Energy Commission's Public Interest Energy Research Program (PIER) through the California Climate Change Center at Scripps Institution of Oceanography, and the CALFED Science Program CASCaDE Project.

A new composite elevation dataset is complete, covering the entire Bay and Delta.

- Based mainly in photogrammetry and LIDAR
- 10-30 cm vertical accuracy
- Horizontal resolution 1-5m
- Work by Tom Coons, USGS (funded by CALFED)
- Napa R. watershed provided by Bill Dietrich and Ionut Iordache, UCB
- no longer missing Petaluma R., Suisun marsh elevation data
- Preliminary Delta LIDAR data courtesy of Joel Dudas

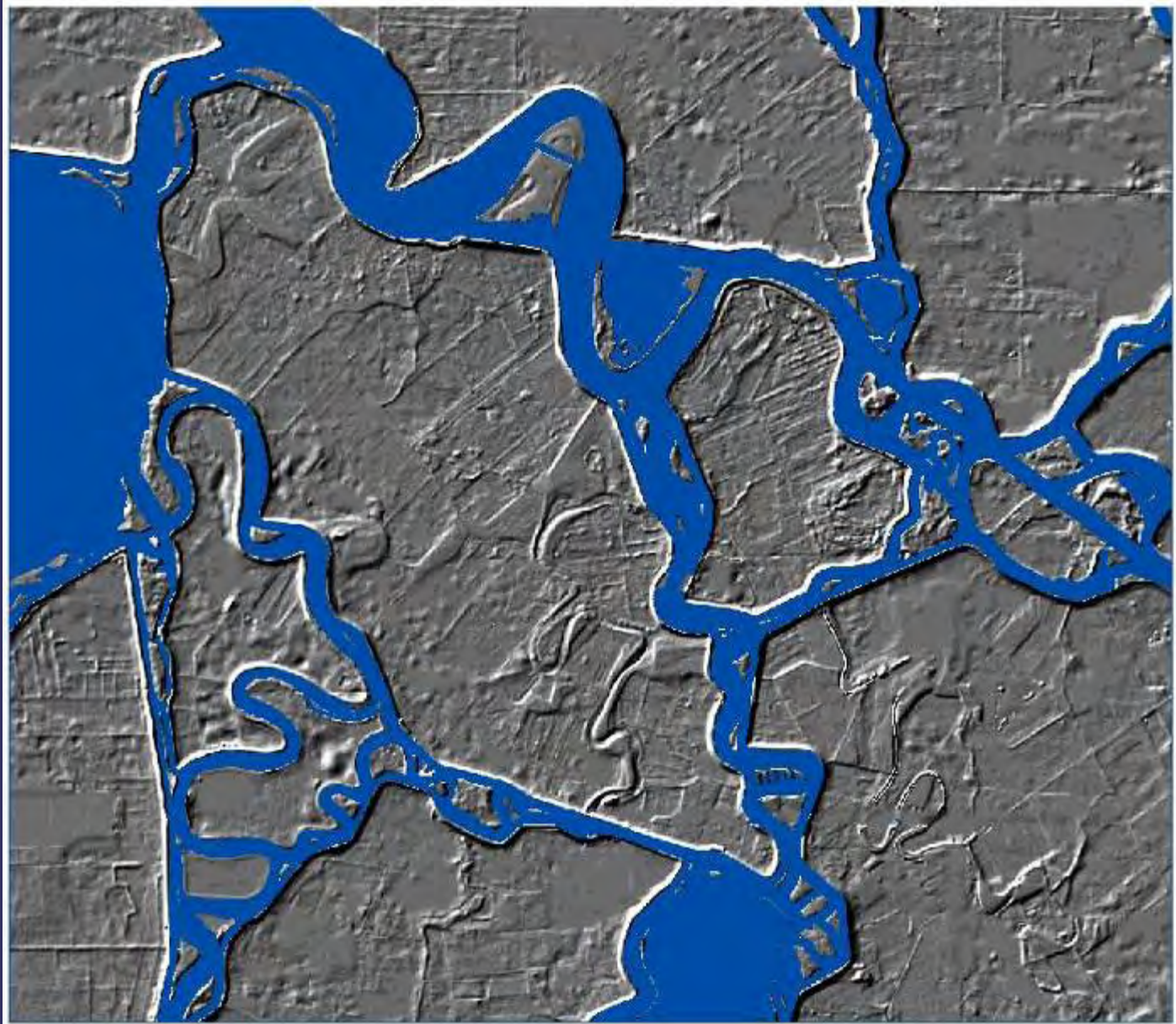


Sample Scene: SF business district and Embarcadero

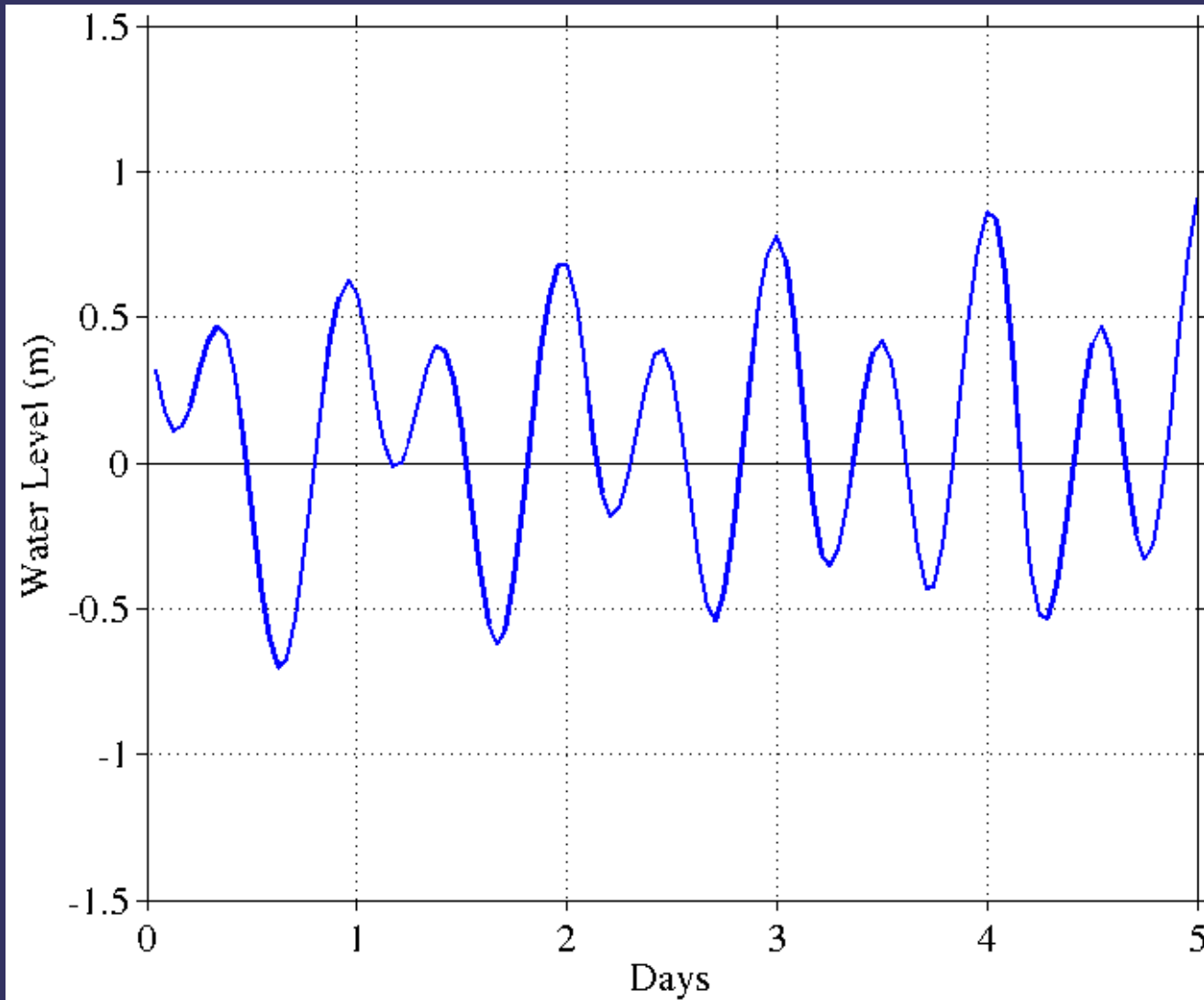


> 3 million points in this scene alone

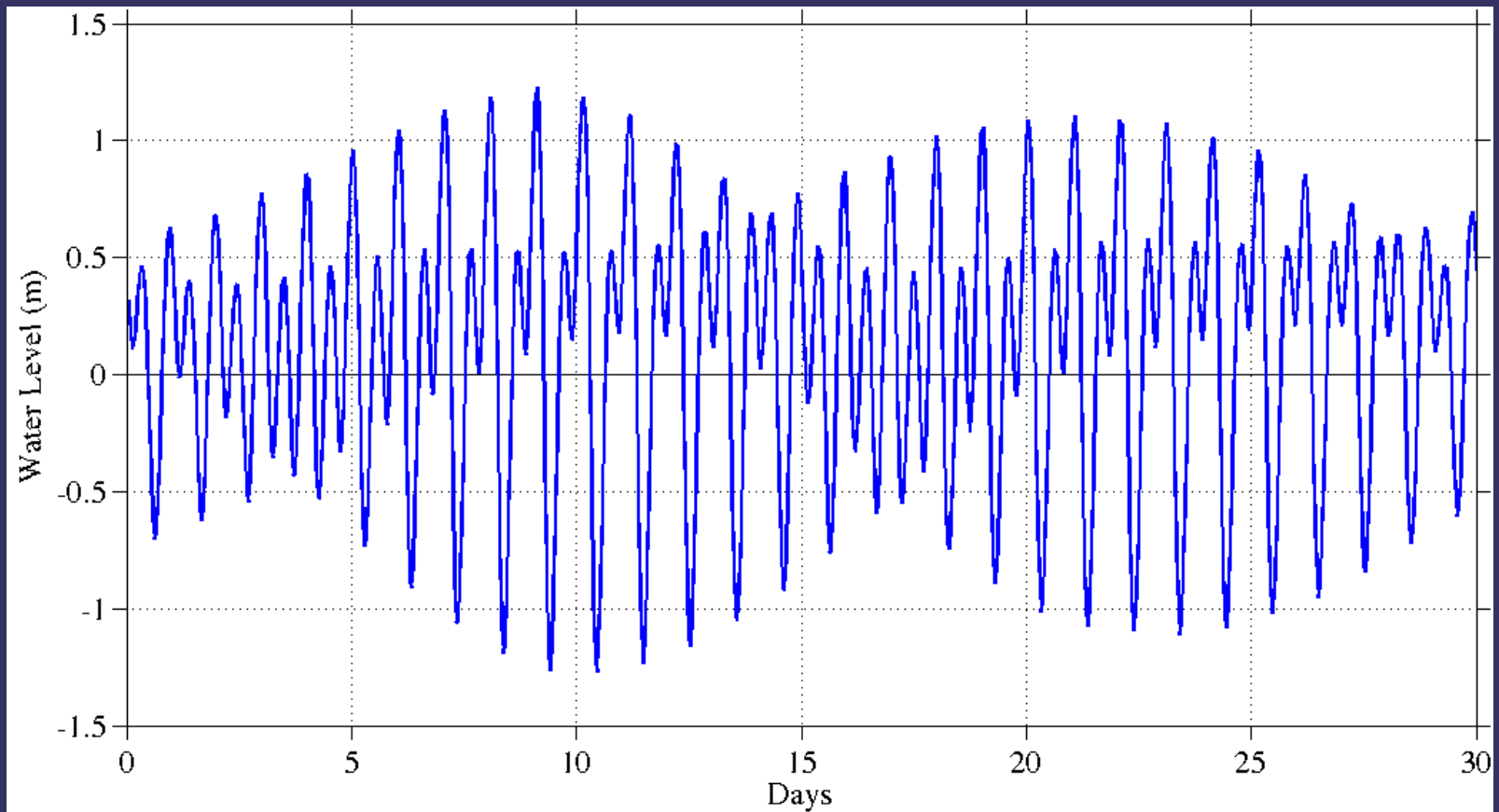
Sample Scene: Delta islands and waterways



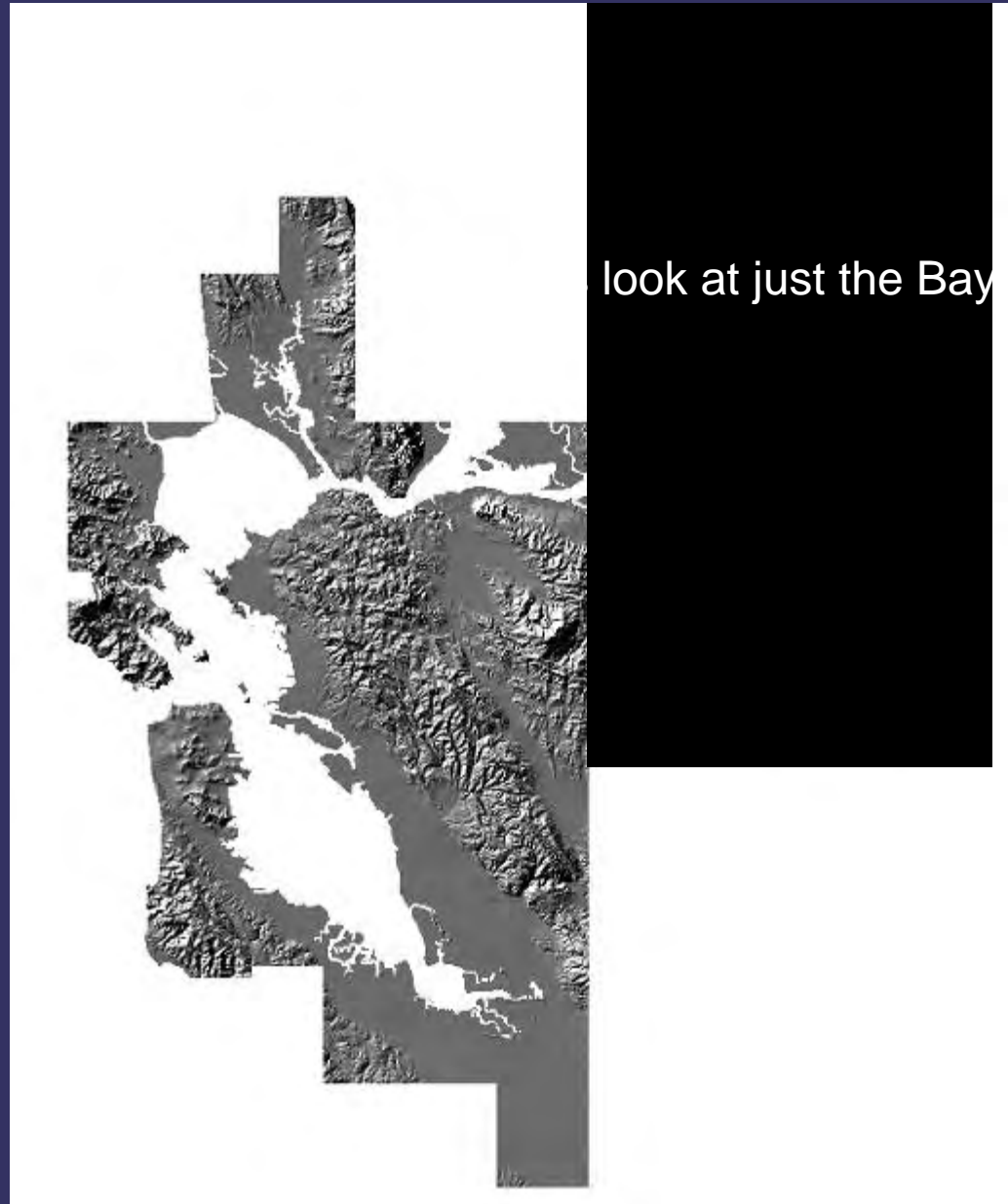
Tides vary around mean sea level on daily time scales...



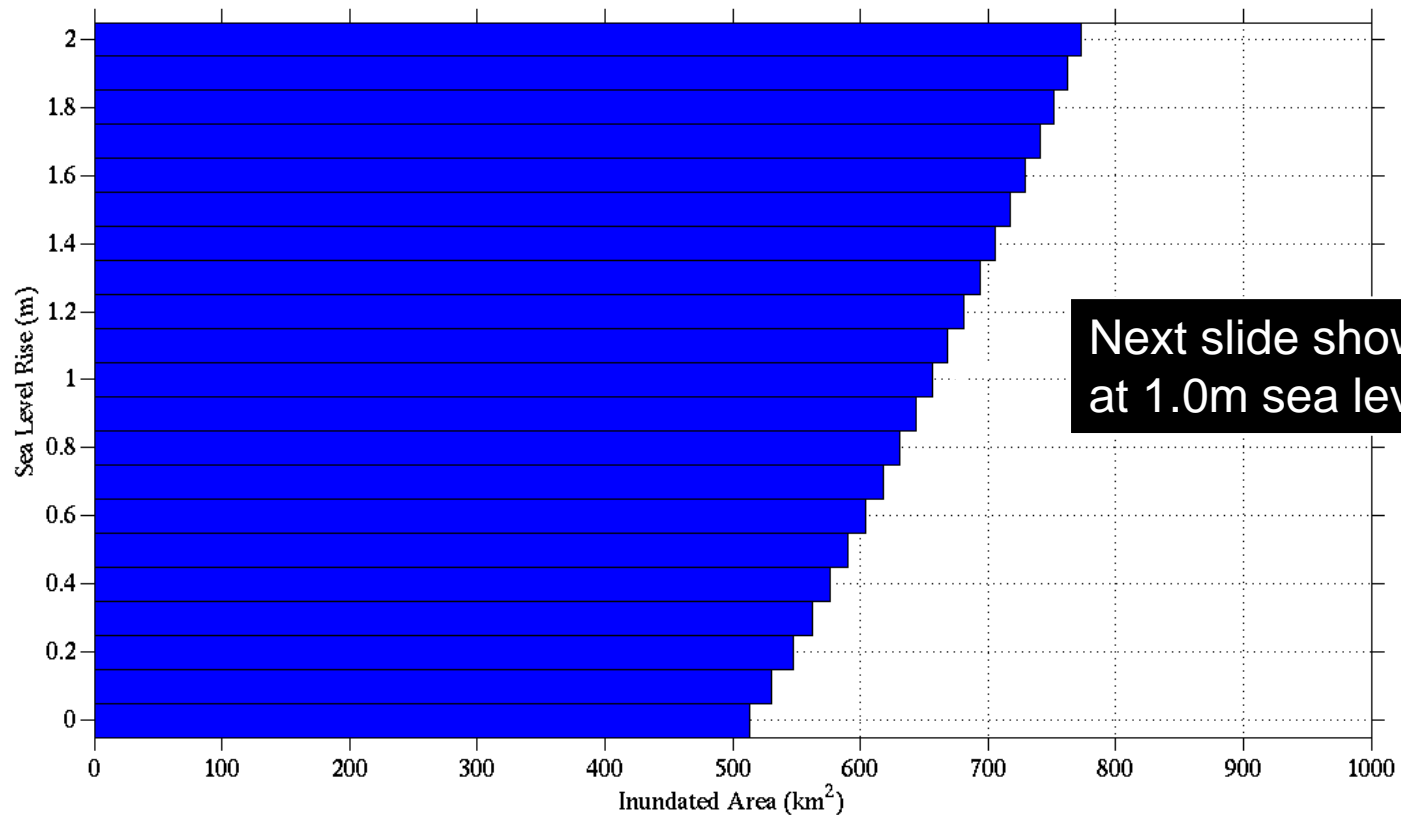
...and also on monthly time scales, with a larger range.



What types of areas are at risk of tidal inundation with sea level rise?



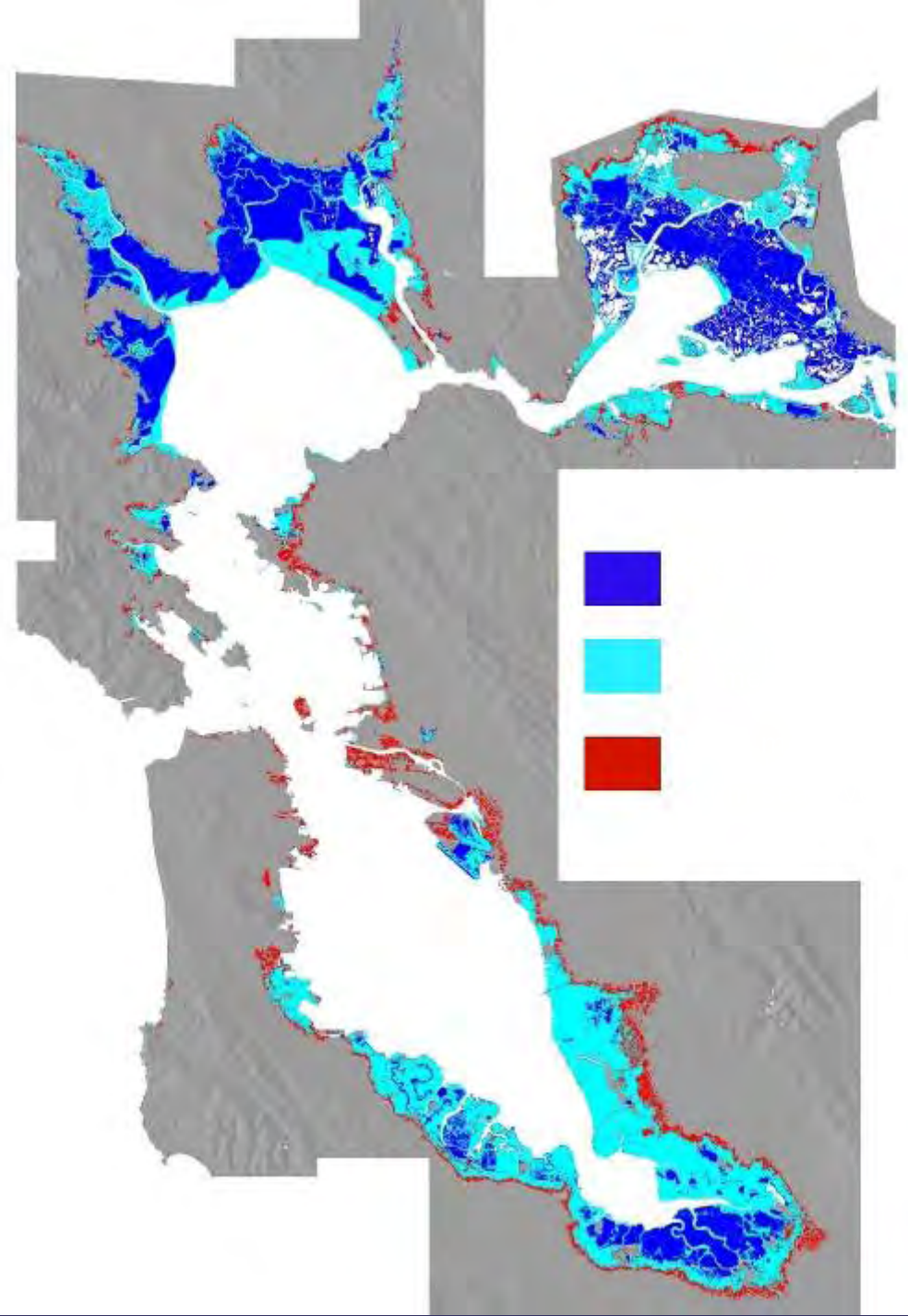
At the monthly time scale, about 500 km² of land are either inundated or protected by levees. This increases by 30% with a 1.0m sea level rise.

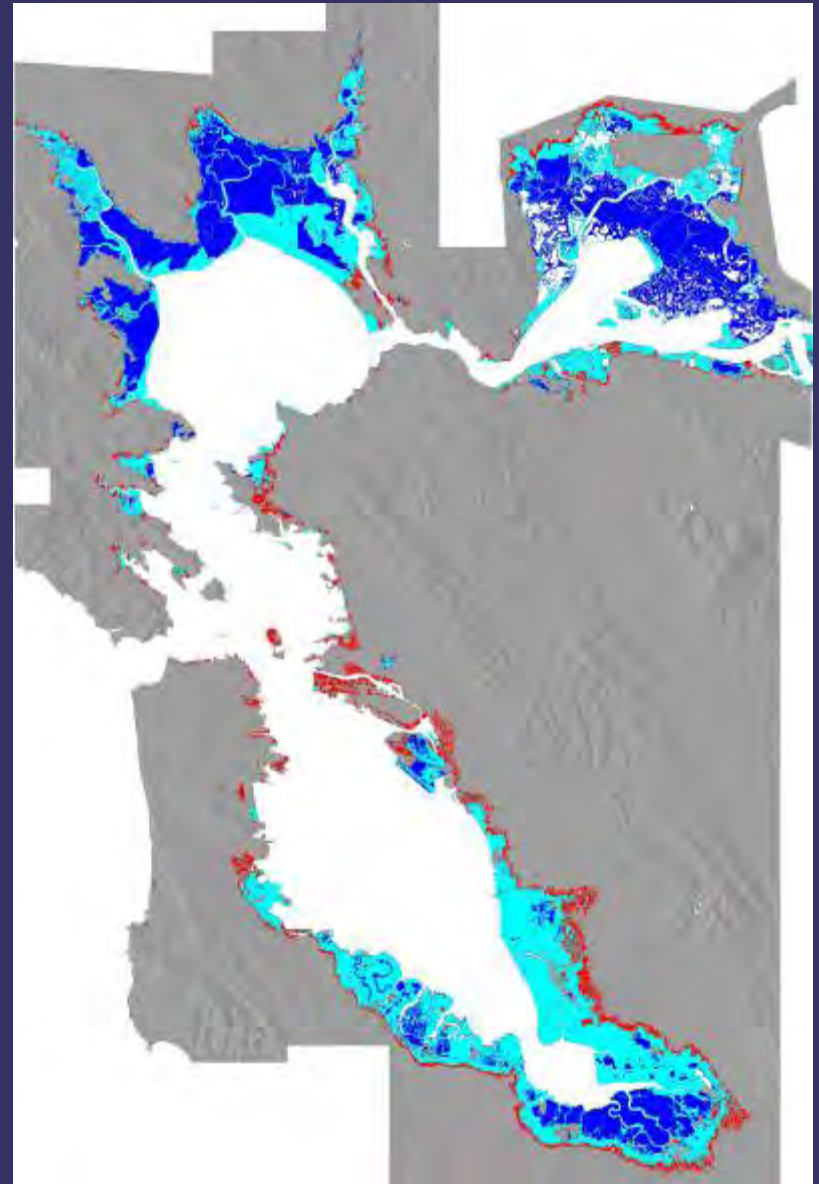


Next slide shows map
at 1.0m sea level rise

The ~150 km² newly at risk of monthly inundation under a 1.0 m sea level rise are shown in red.

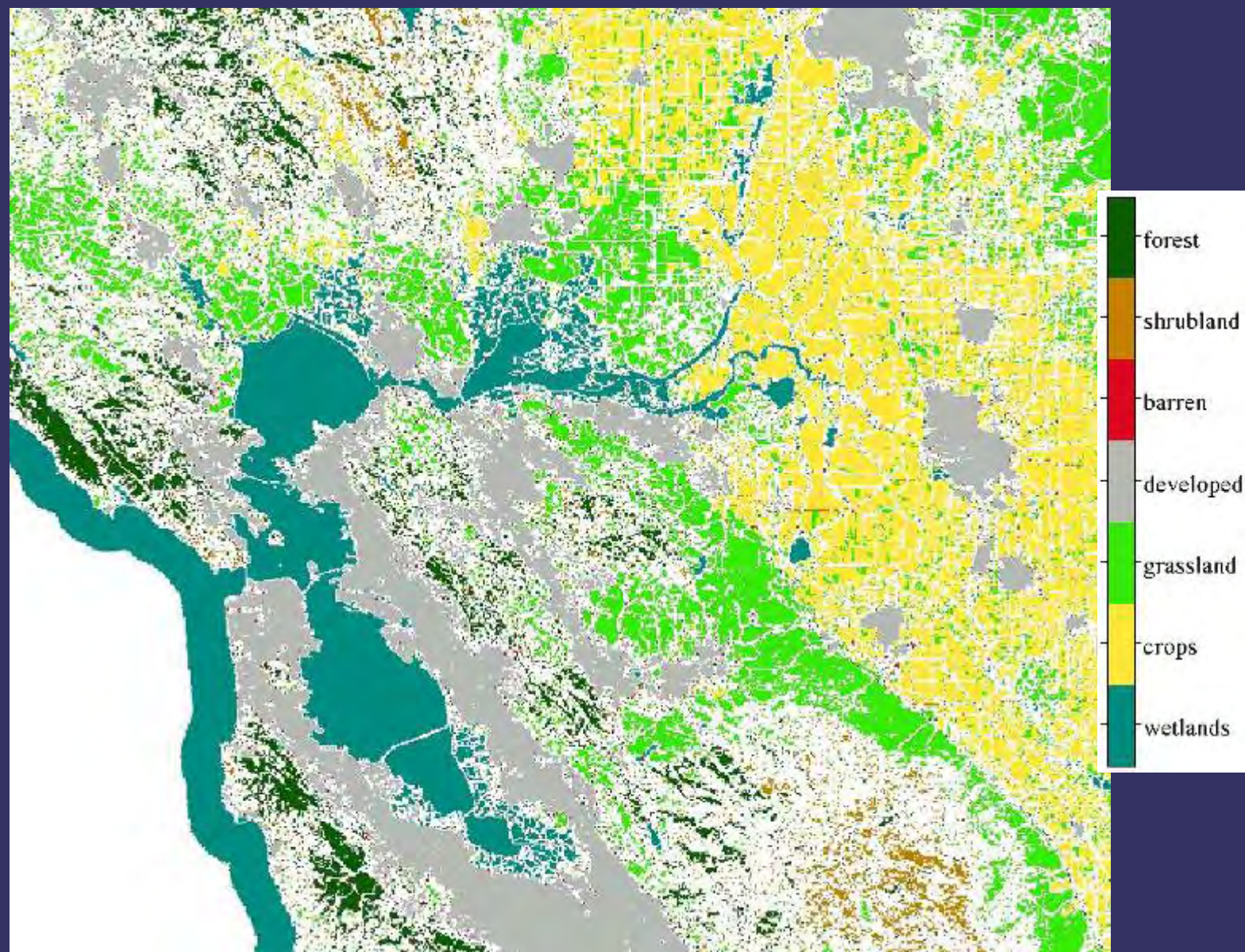
Most of these areas are currently protected by levees. They would be inundated only if those levees fail or are overtopped.



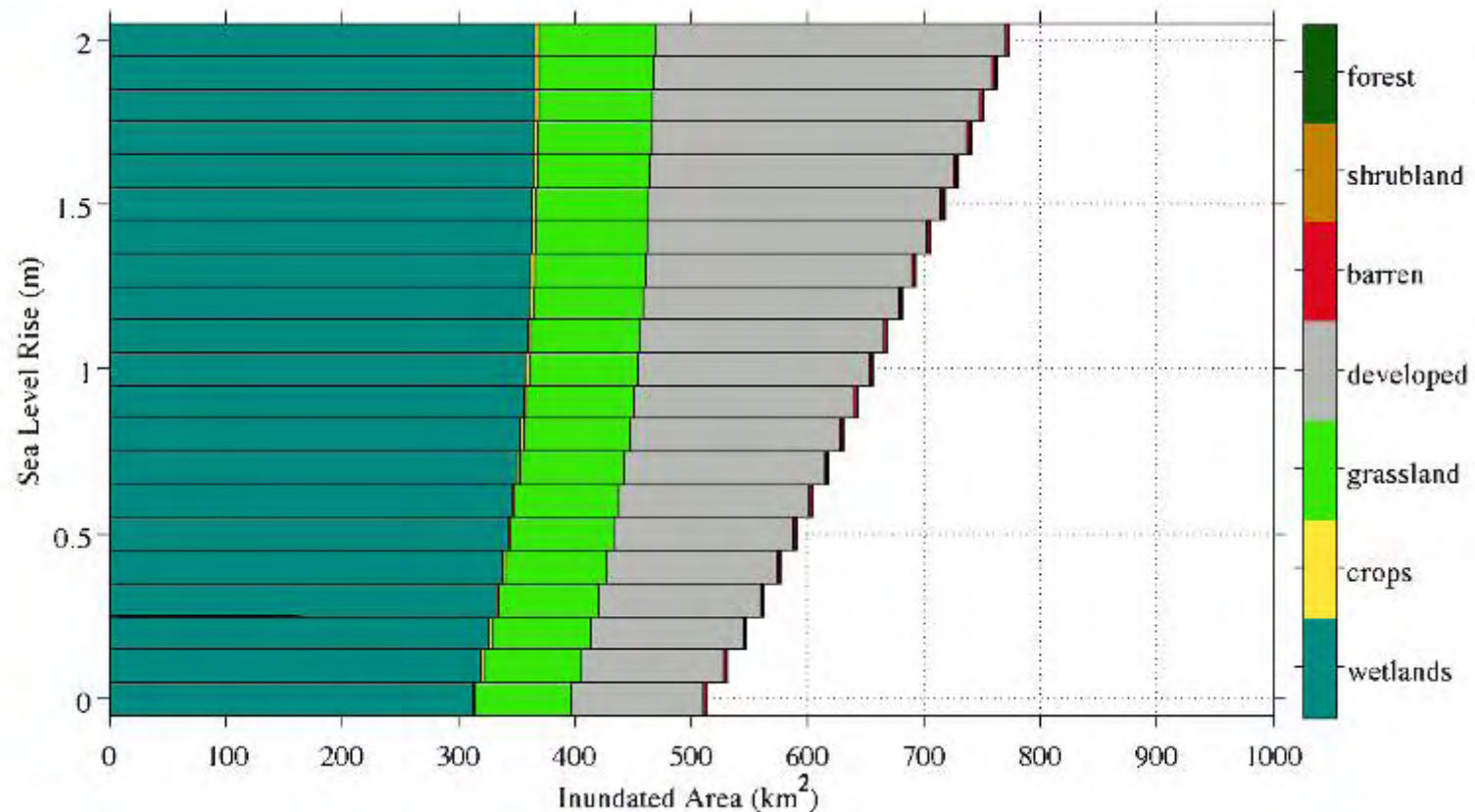


Between the Devil and the Deep Blue Bay,
Harold Gilliam, 1969

An updated land cover dataset has also become available: NLCD2001

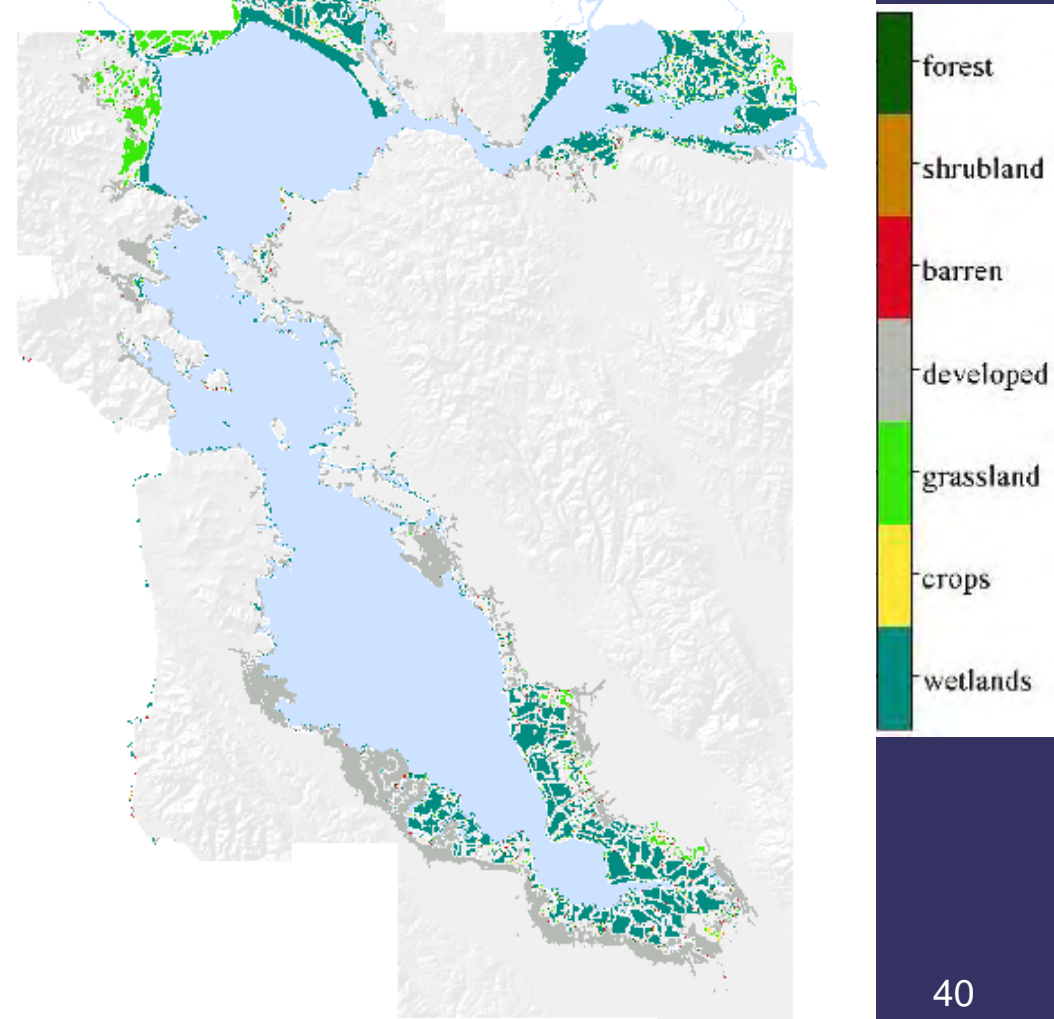


Areas of different land cover types at risk of monthly inundation



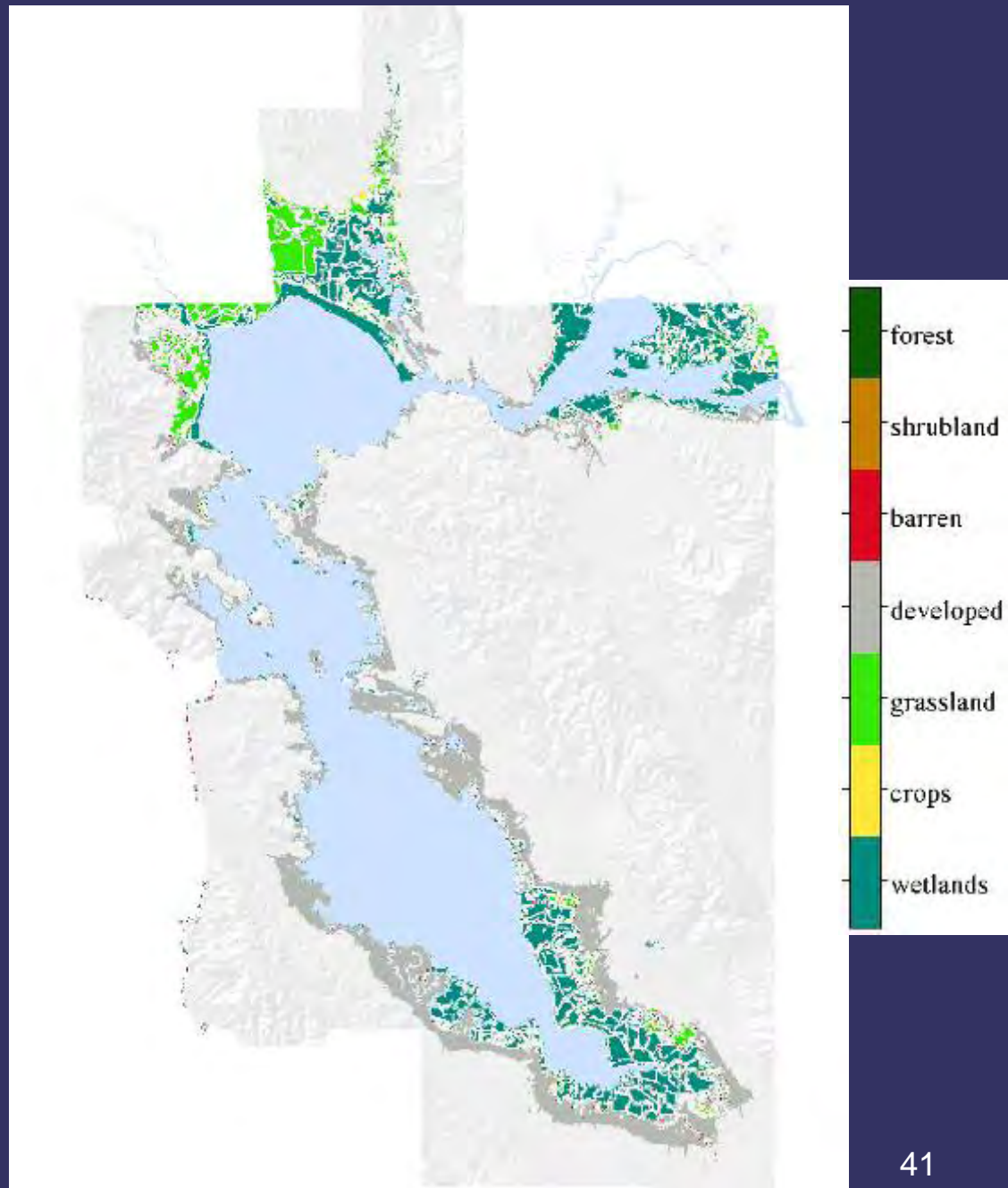
Marsh, grasslands— little change. Developed areas-- big increase.

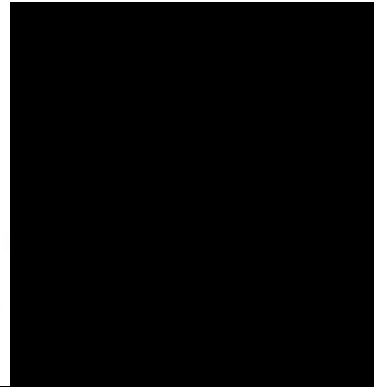
Areas below present
mean monthly high tide



Areas below mean
monthly high tide with
1.0 m sea level rise

Main increase in at-risk
areas are in the “developed”
land cover class.

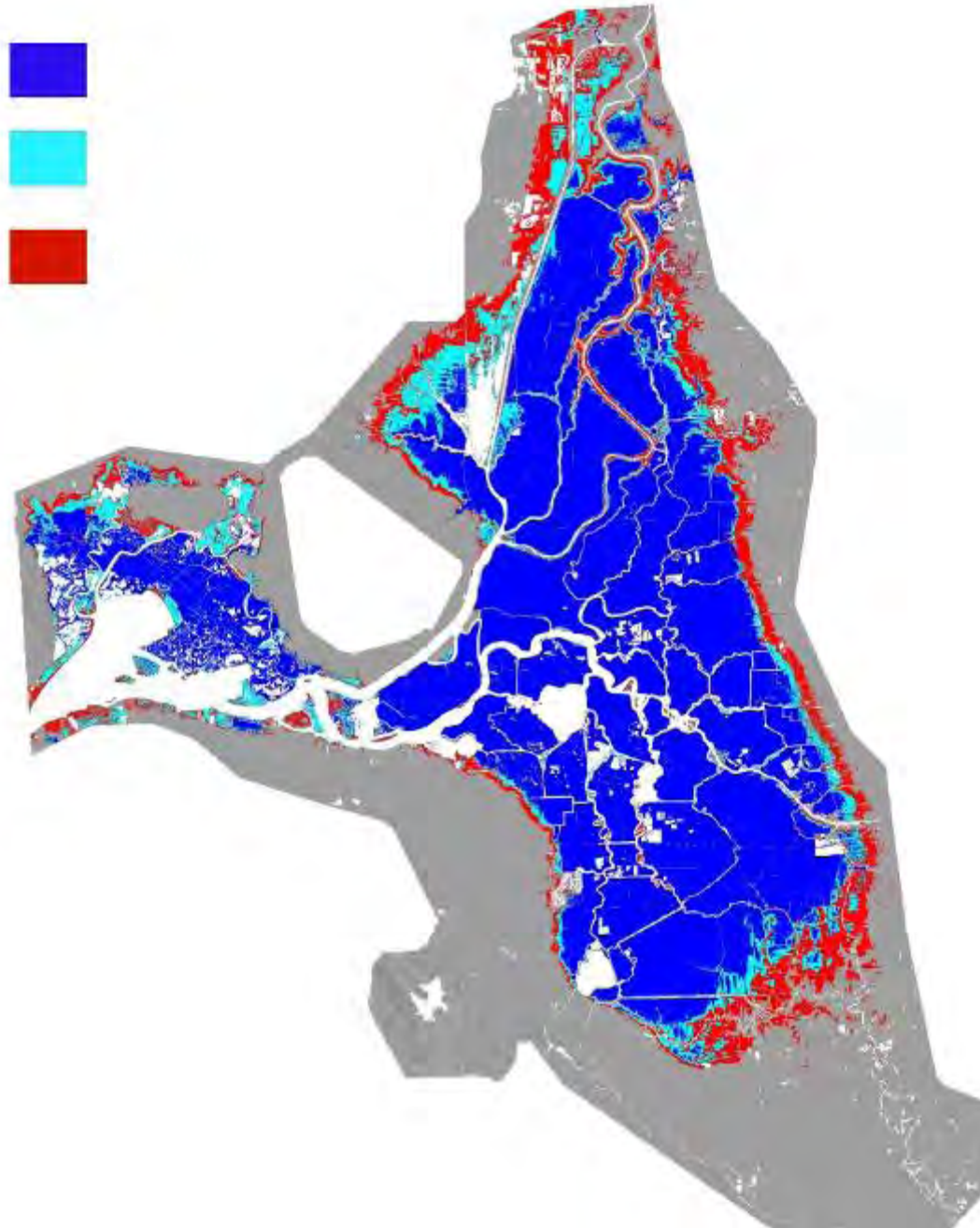




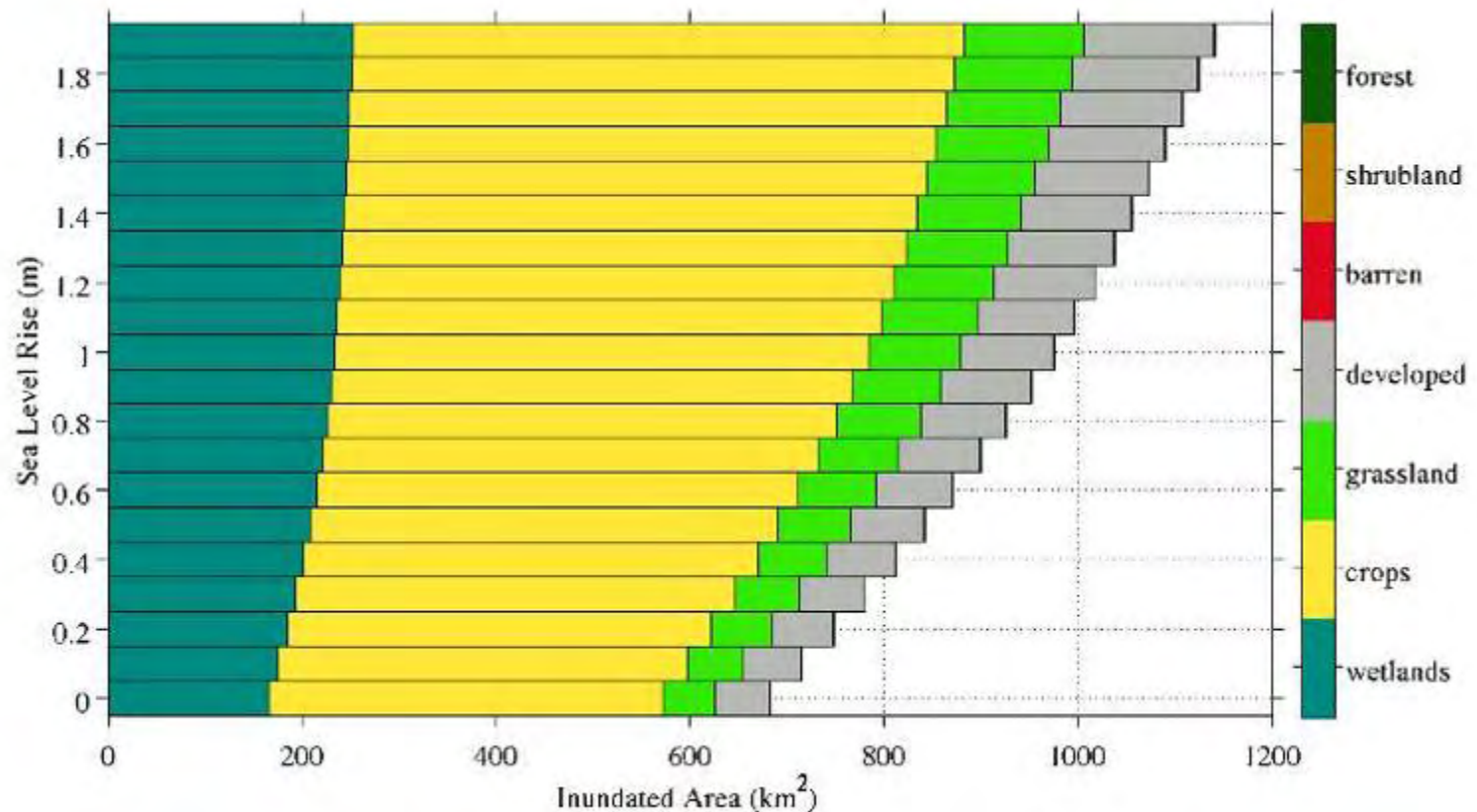
Next let's look at the Delt

About 300 km² newly at risk of monthly inundation under a 1.0 m sea level rise are shown in red.

Most of these areas are currently protected by levees. They would be inundated only if those levees fail or are overtopped.

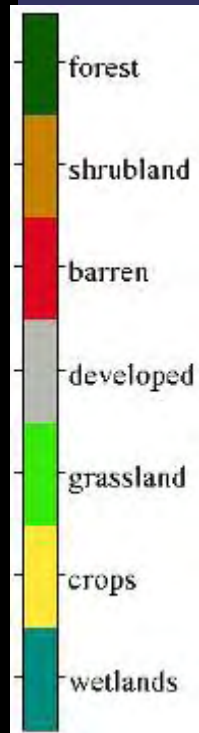
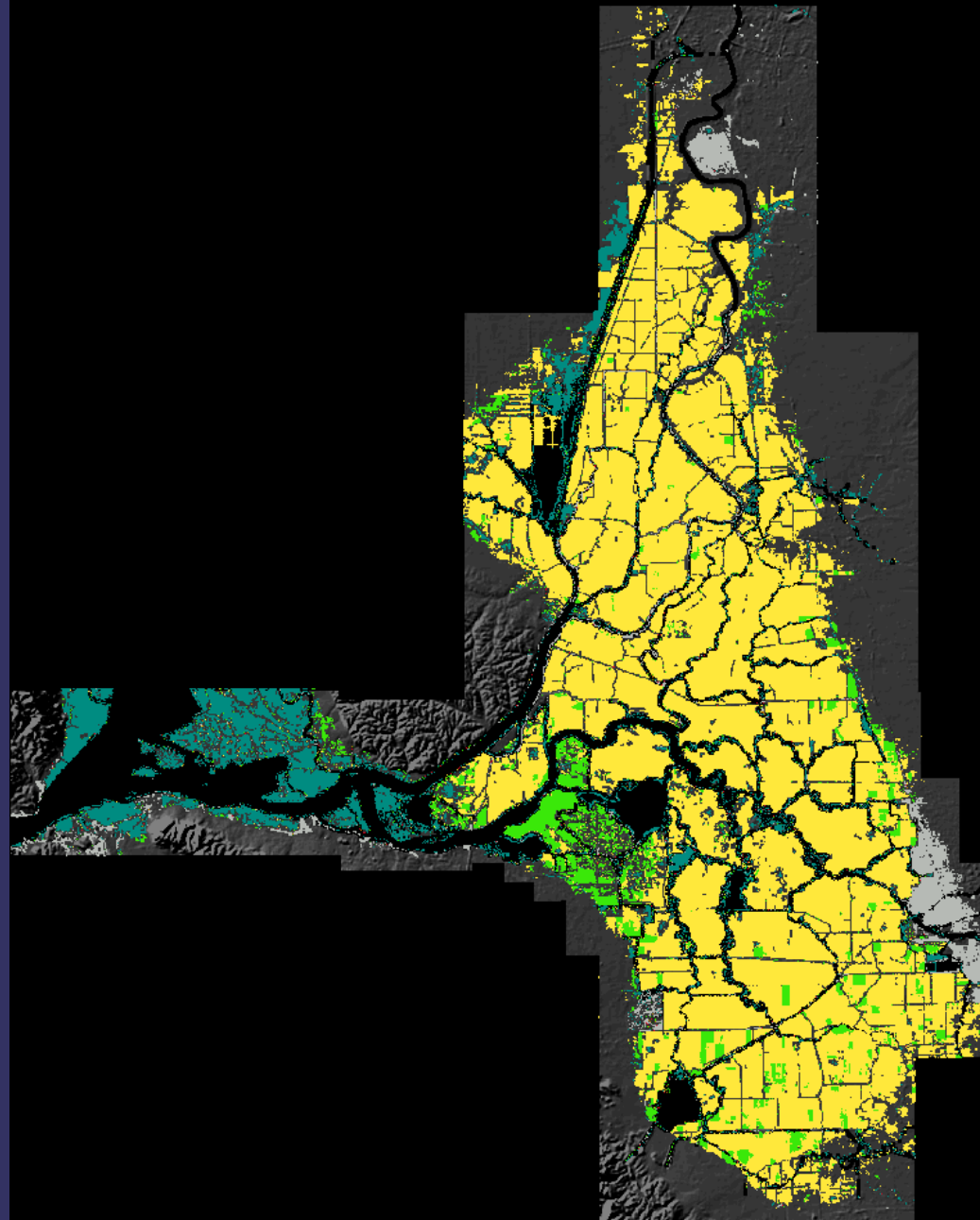


Areas of different land cover types subject to MONTHLY inundation
(areas currently below sea level, mainly croplands, are excluded for clarity from this figure only)



All categories increase, but big changes are in cropland.

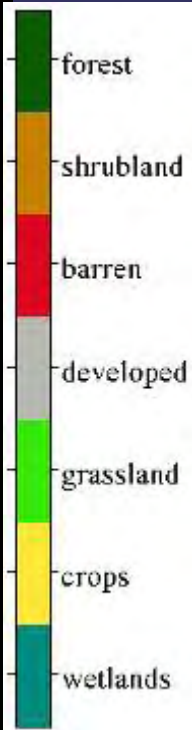
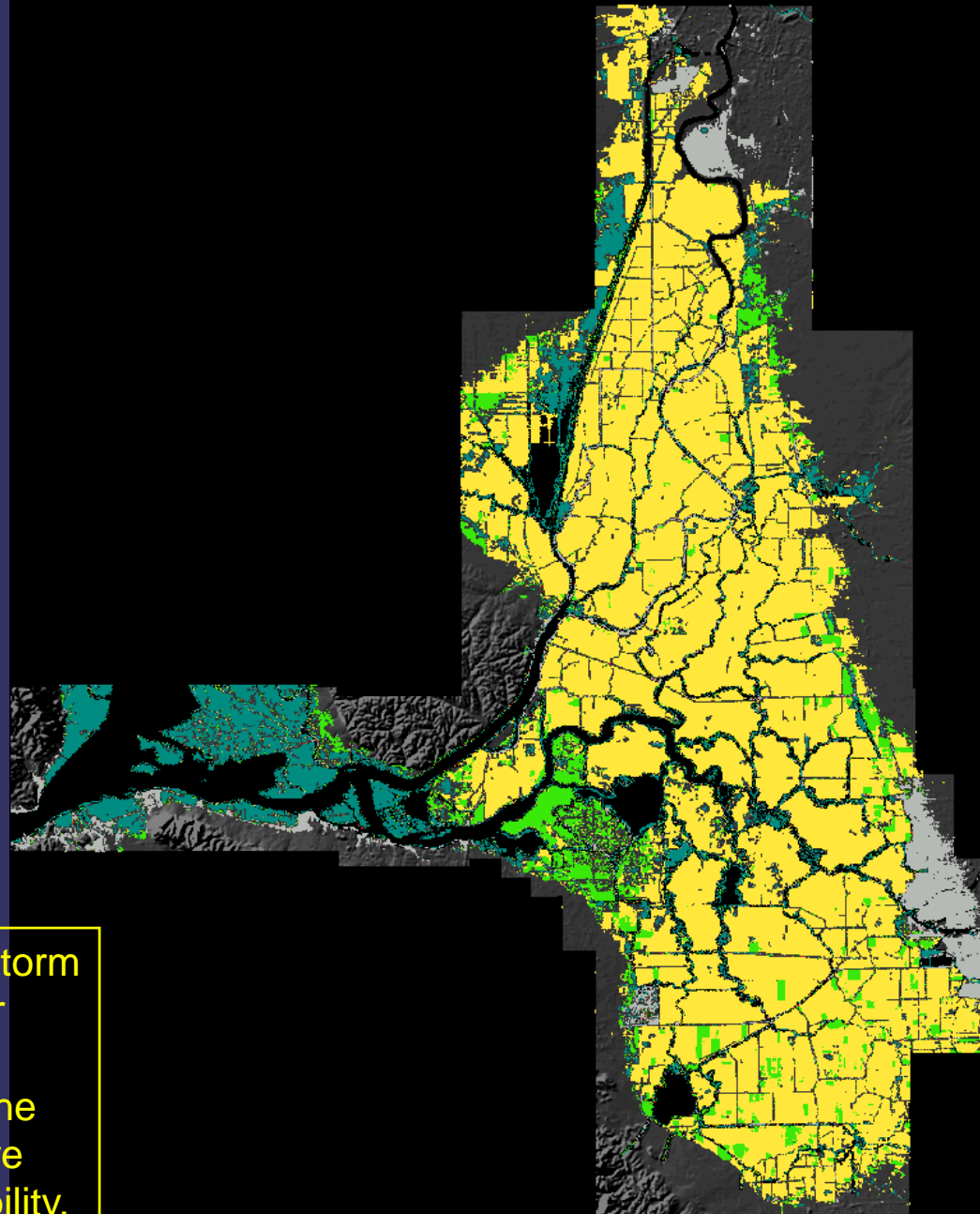
Areas below present
mean monthly high tide



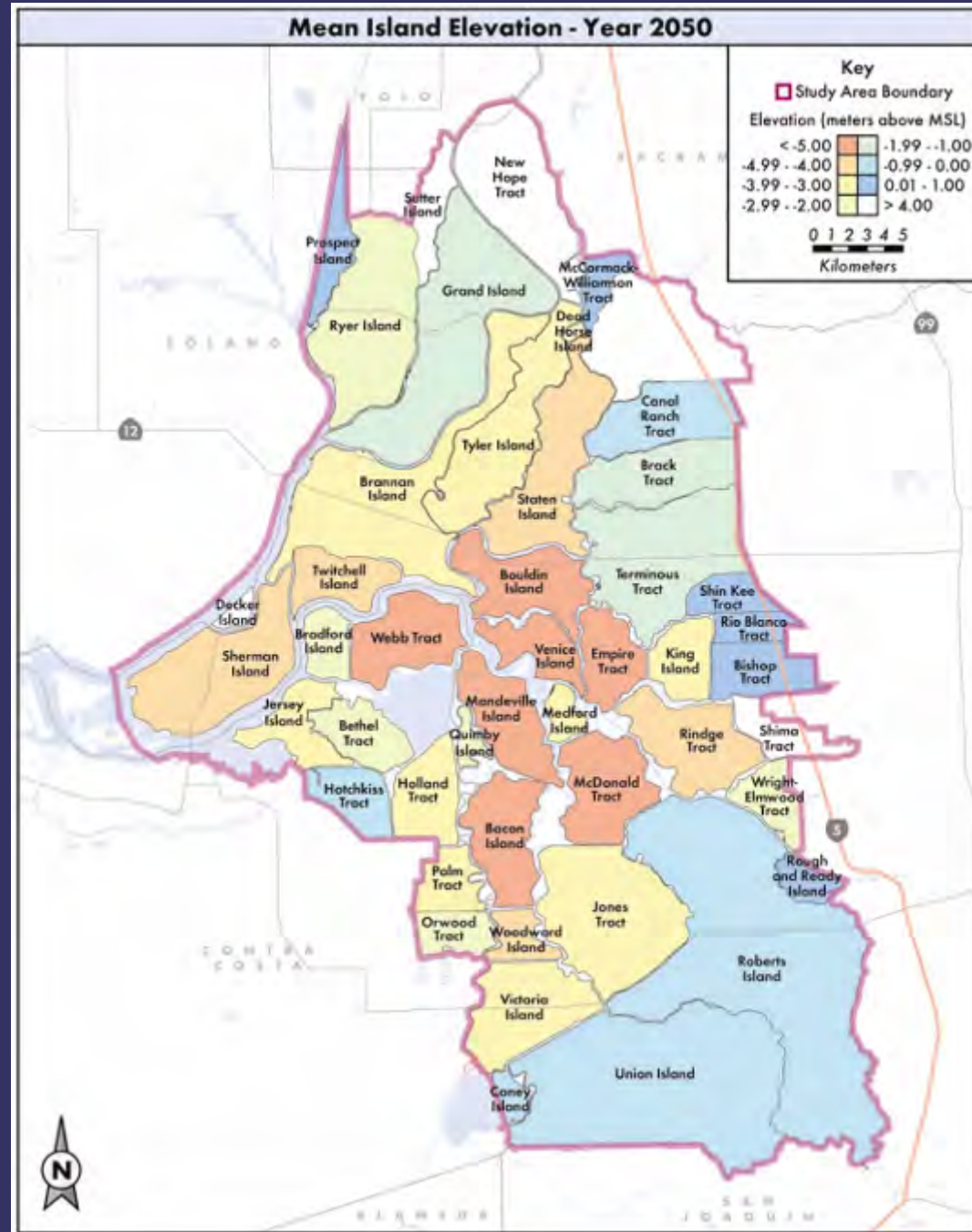
Areas below mean
monthly high tide with
1.0 m sea level rise

Main increase in at-risk
areas are in the “crops”
cover class.

Not included yet– effects of storm
surges, river inflows on water
levels. River inflows have a
stronger effect than tides in the
Delta, and extreme events are
most important for levee stability.



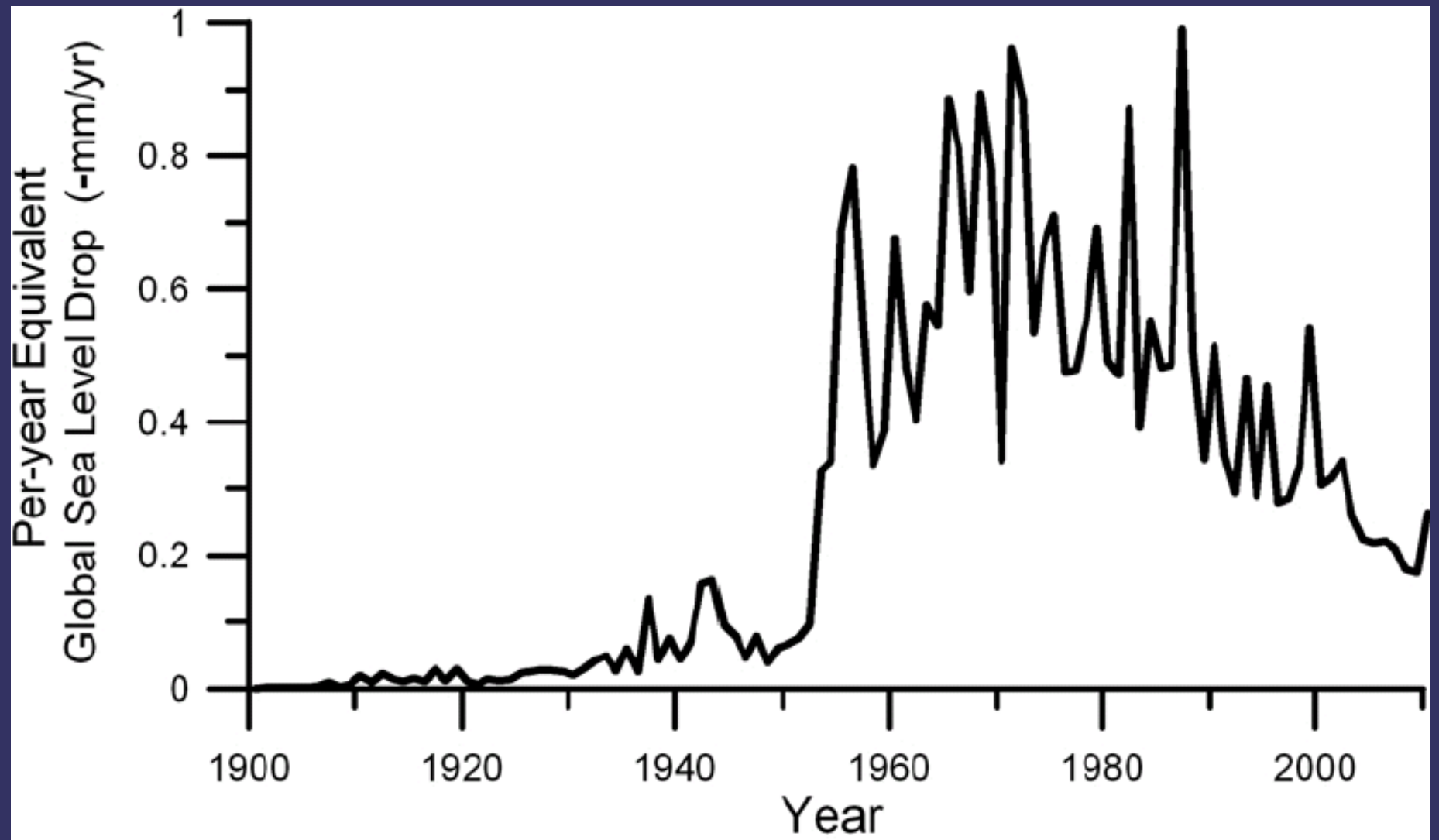
More work to do on those “islands” below sea level...



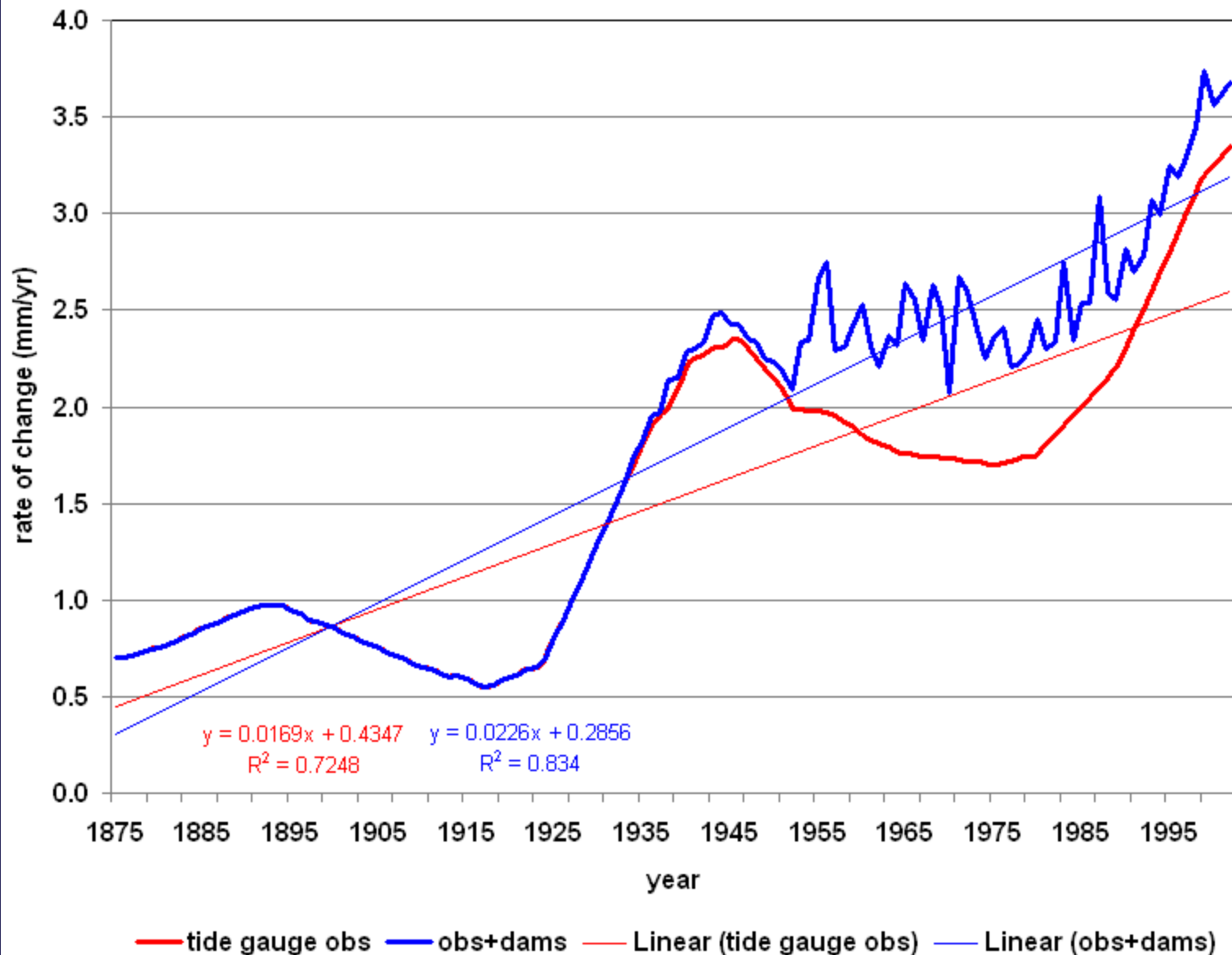


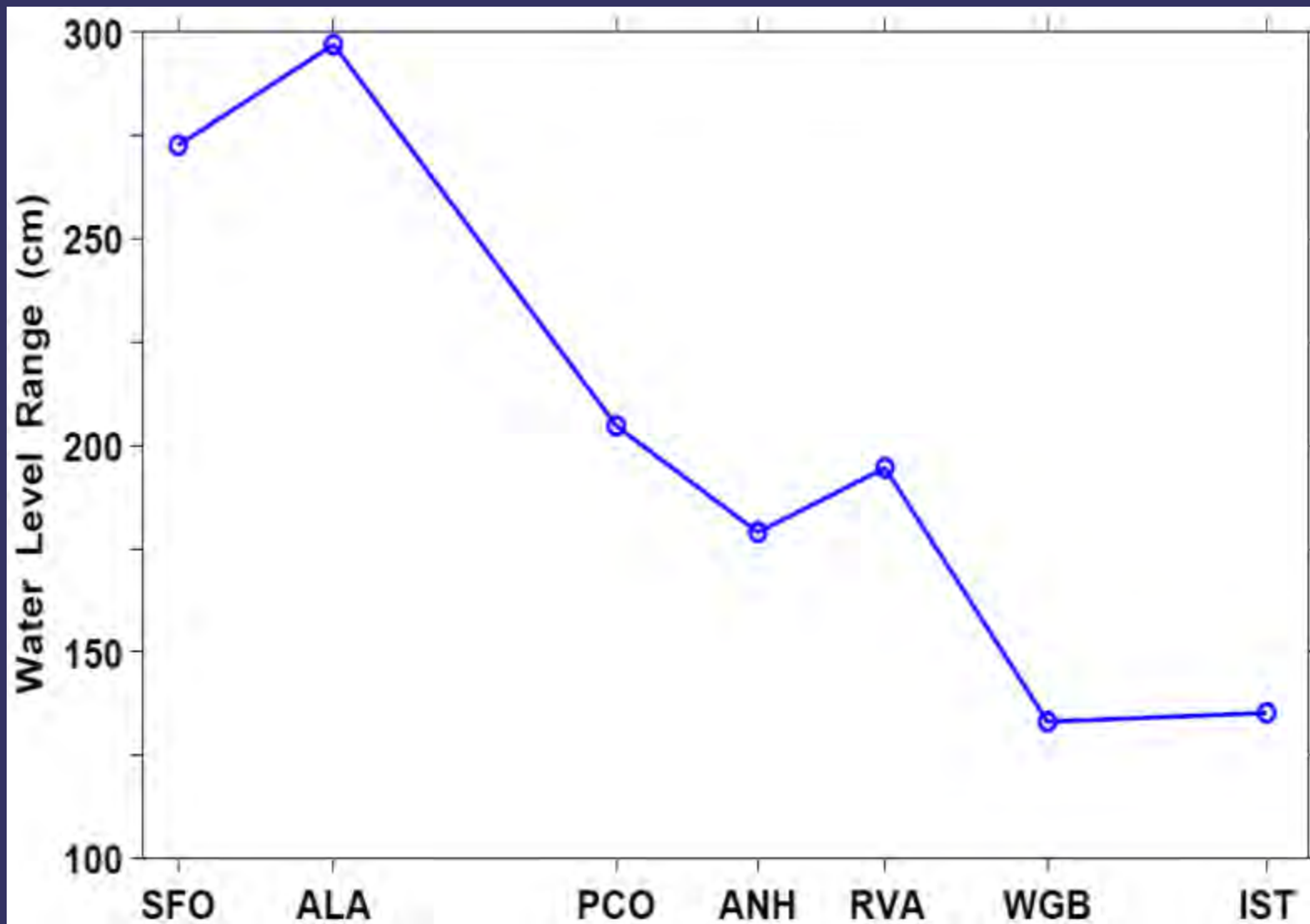
Preliminary results:
Accurate elevation data permits
the calculation of useful
information regarding potential
levee breaches.

Name	%vol	%prism
Grand Island	10	16
Tyler Island	7	10
Brannan Island	14	18
Staten Island	9	9
Bouldin Island	6	7
Twitchell Island	4	4
Sherman Island	9	13
Webb Tract	6	7
Empire Tract	4	5
Bradford Island	2	3
Venice Island	4	4
King Island	3	4
Mandeville Island	6	7
Jersey Island	2	4
Medford Island	1	2
Rindge Tract	7	9
Bethel Tract	2	4
Quimby Island	1	1
McDonald Tract	7	8
Holland Tract	3	5
Bacon Island	6	7
Palm Tract	2	3
Jones Tract	10	14
Woodward Island	1	2
Orwood Tract	1	3
Victoria Island	5	8
...many other islands not shown		



sea level change from tide gauge observations (red)
adjusted for effects of runoff impounded in dams (blue)





Tide range from San Francisco near Golden Gate northeastward to Sacramento.

The ranges were estimated by subtracting the 10 lowest from the 10 highest water level values from all available data during the low river flow May-September periods during 1991 and 1992, except Walnut Grove (WGB) whose record begins in 1993, so the May-Sep 1993 period was used.

GREATEST COASTAL IMPACTS

“High” High-Tide

in conjunction with

Extreme Storm - Forced Sea Levels

Extreme Surge + Extreme Waves during High Tide

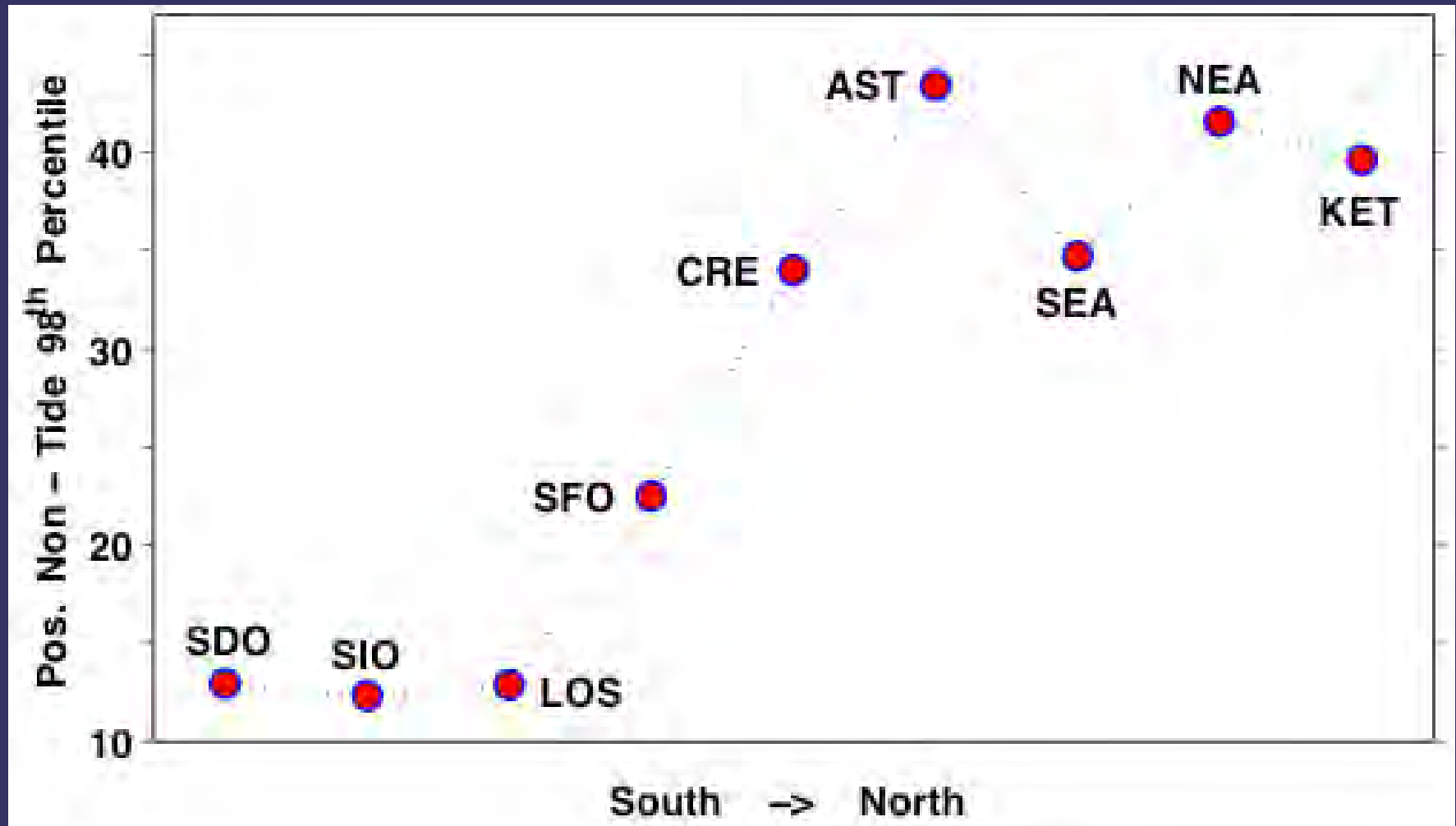
Ocean Beach , February 1983



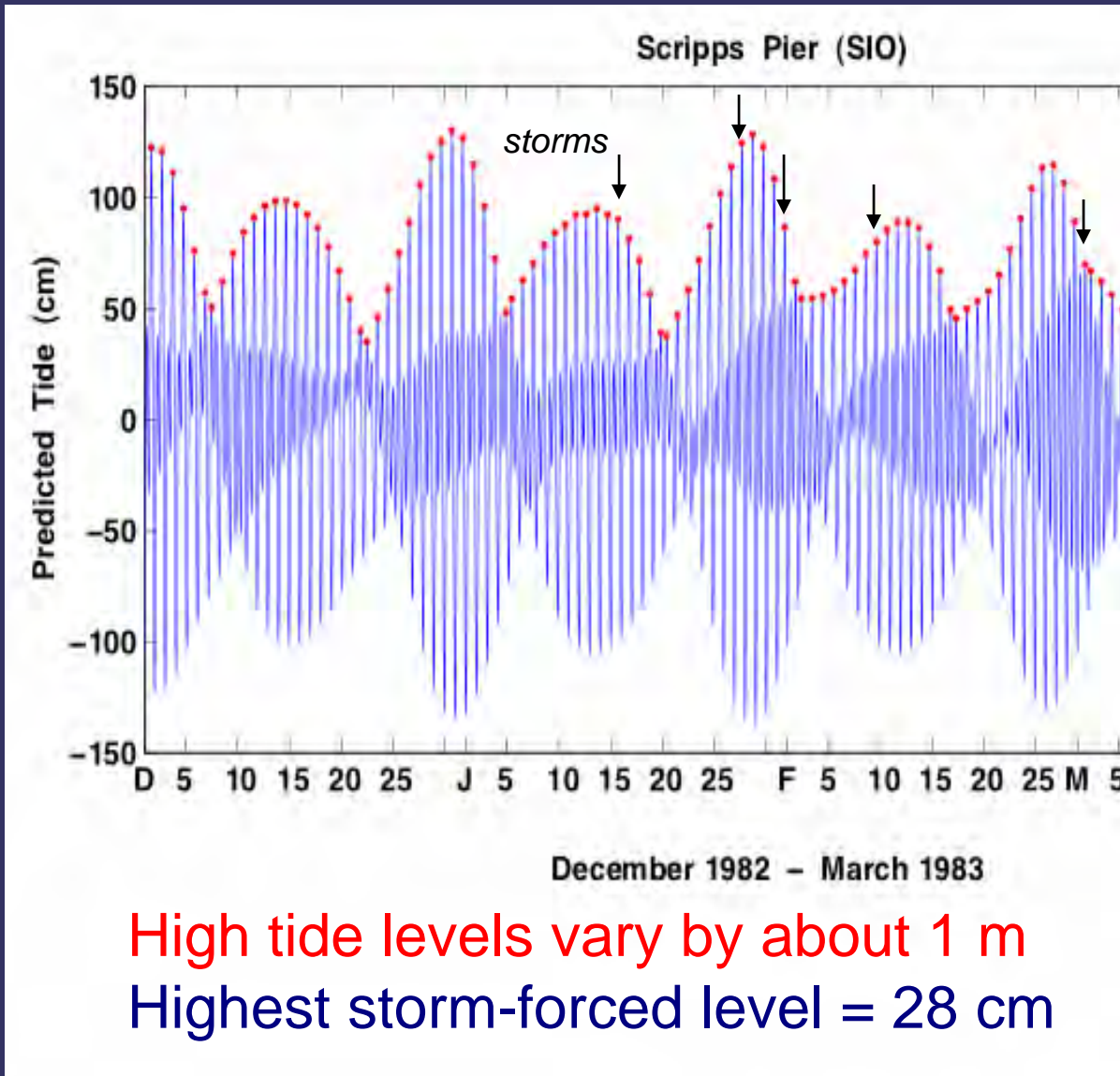
Extreme storm-forced sea levels during an extreme tide

Variability of Non - Tide Extremes along the West Coast

San Francisco is intermediate, with 98th %ile levels at about 20cm



Coincidence of storms and high tides in Winter 1983 -- heavy coastal damage

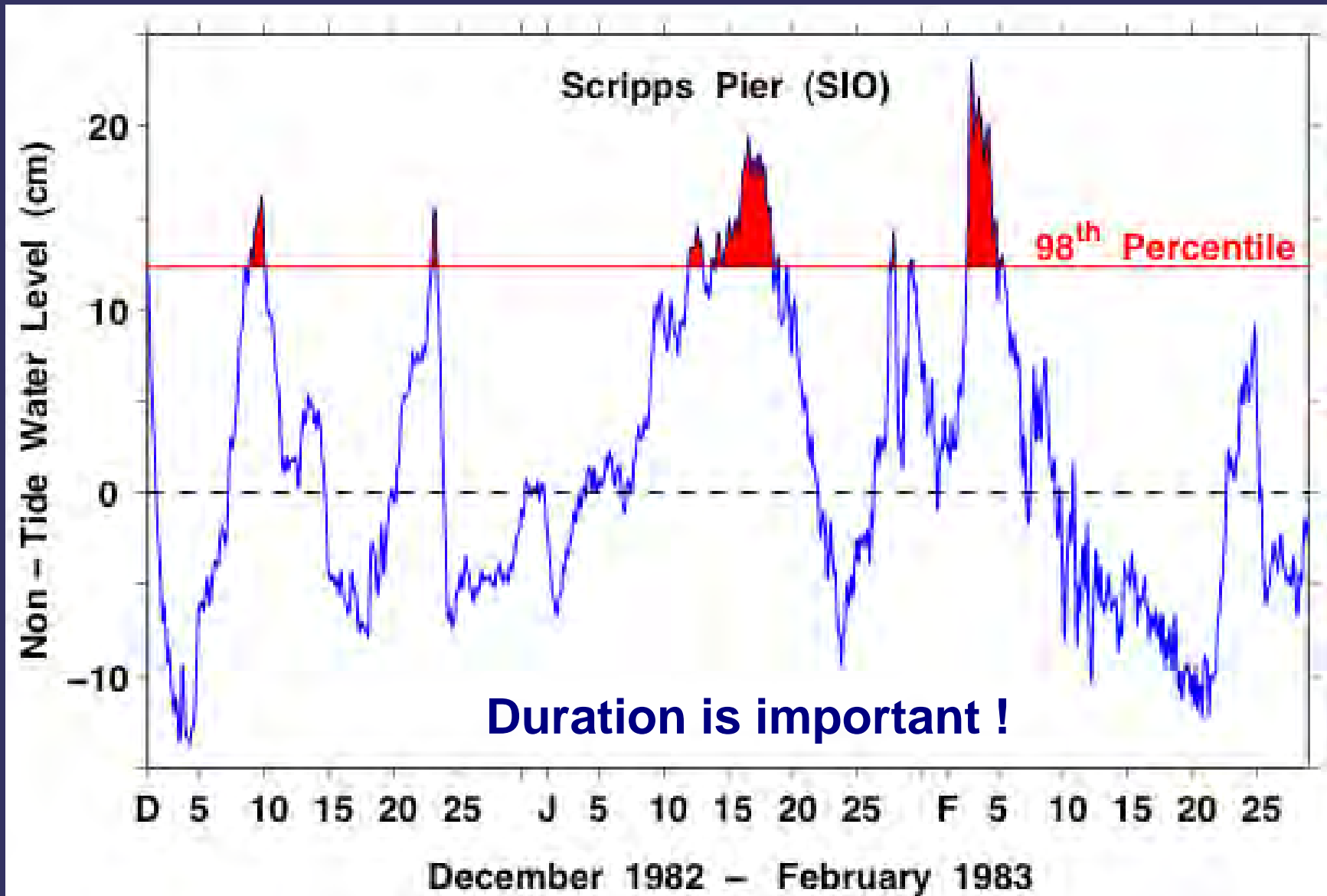


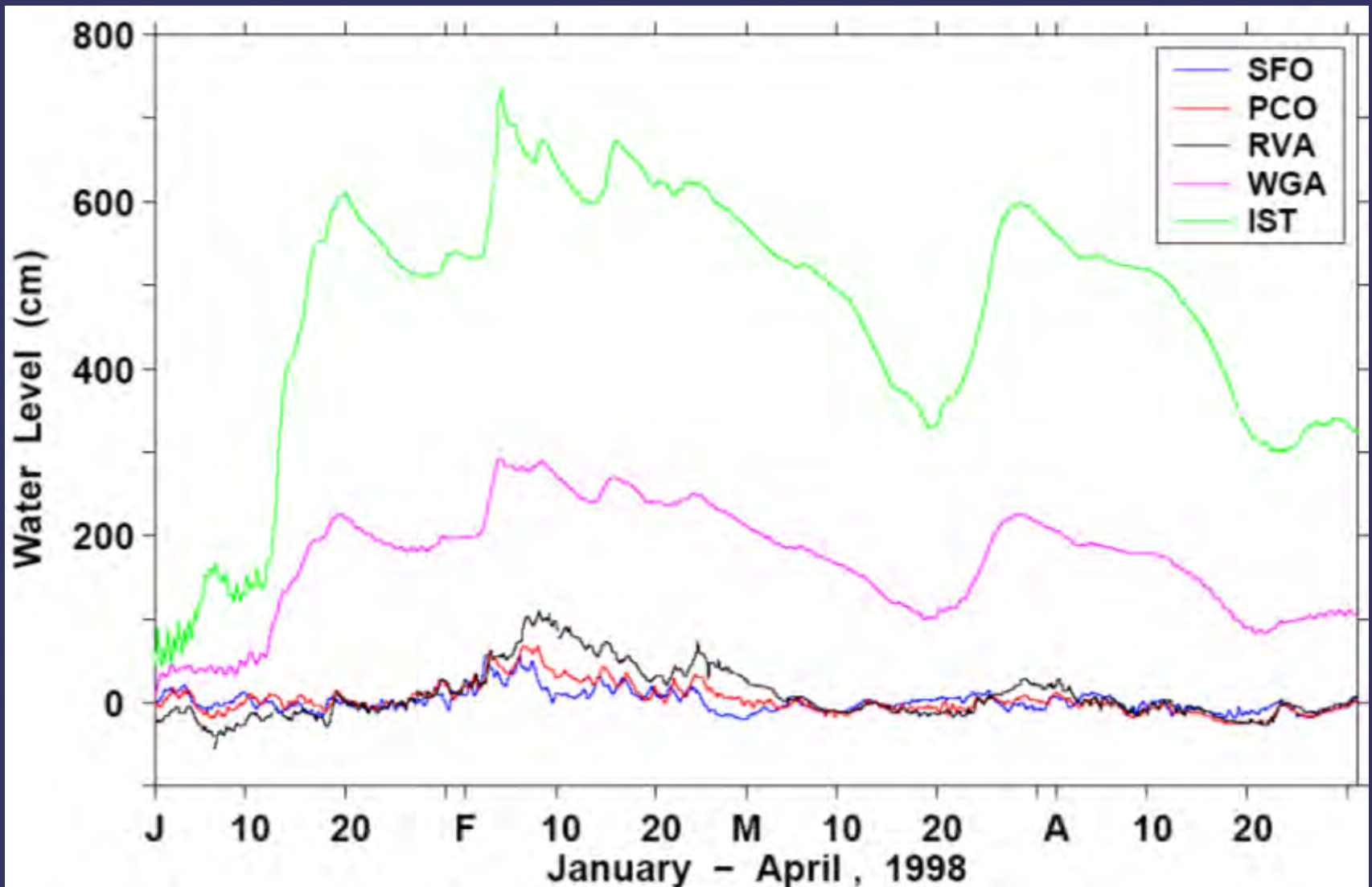
Two high tides and two low daily tides, unequal in amplitude.

Monthly tidal changes dominated by spring-neap cycle, with two periods of relatively high tides (springs) around full and new moon. One spring tide range per month is usually higher than the other on this coast.

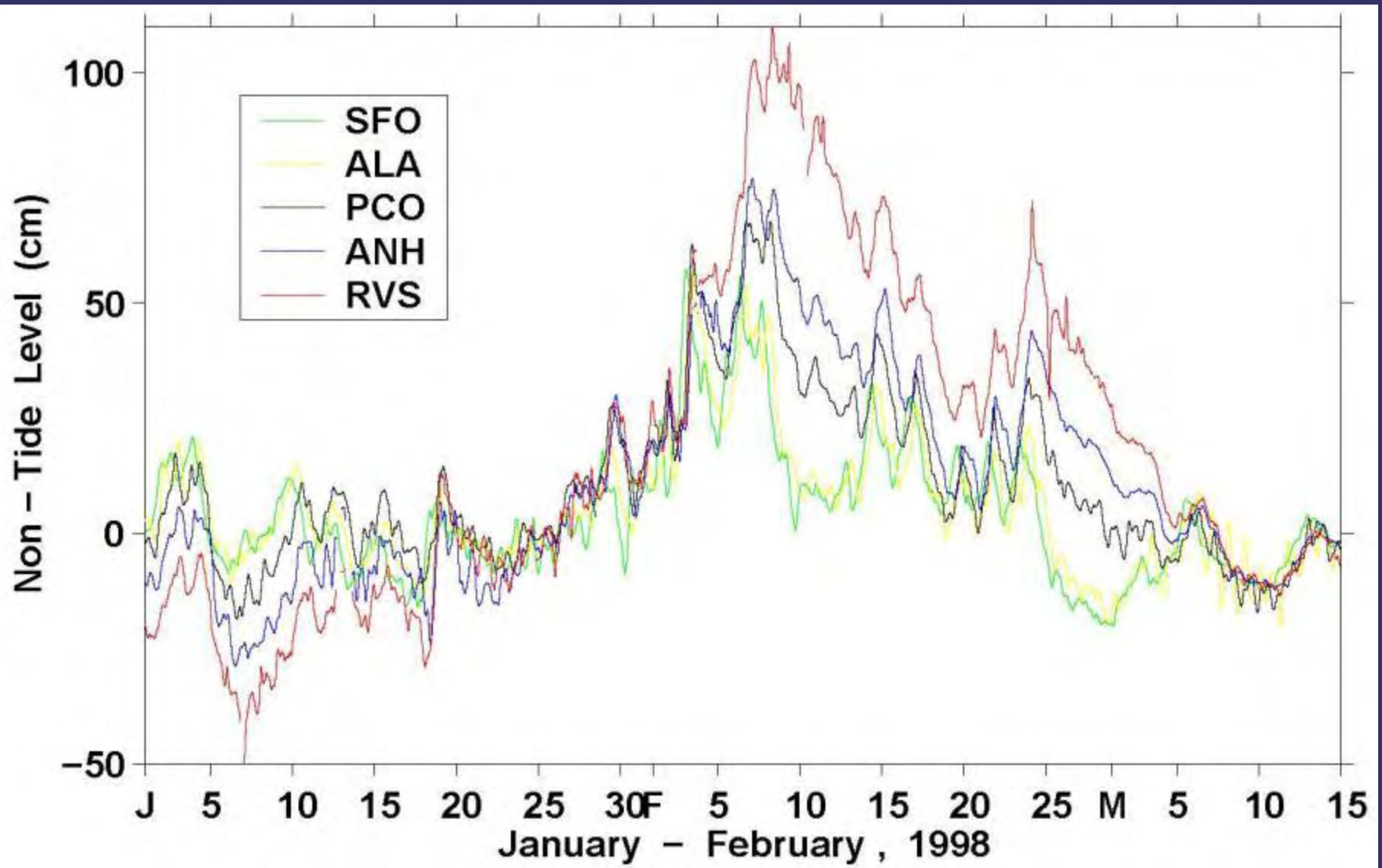
The highest monthly tides in the winter and summer months are higher than those in the spring and fall as a result of lunar and solar declination effects.

Extreme Non-Tide Levels

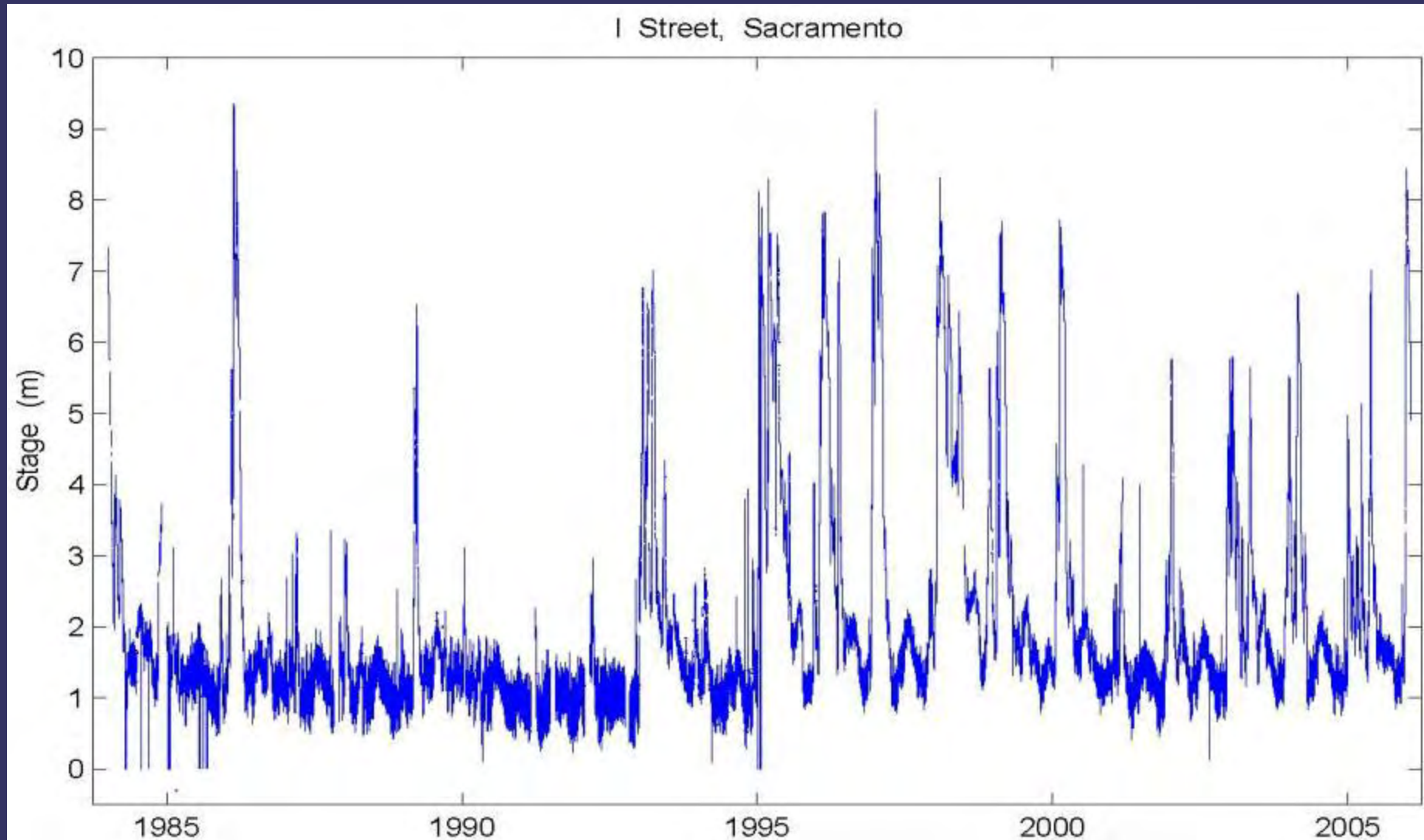




Non-tide water levels (cm) at stations from
 Water levels, tide removed, in San Francisco Bay/Delta during 1998
 San Francisco eastward to Sacramento, Jan-Apr 1998.
 data are tide/water levels from San Francisco (SFO) to Sacramento (IST)
 Stations incl San Francisco at Golden Gate (SFO), Port Chicago (PCO), Rio Vista (RVA),
 Walnut Grove (WGA), and Sacramento at I Street (IST).



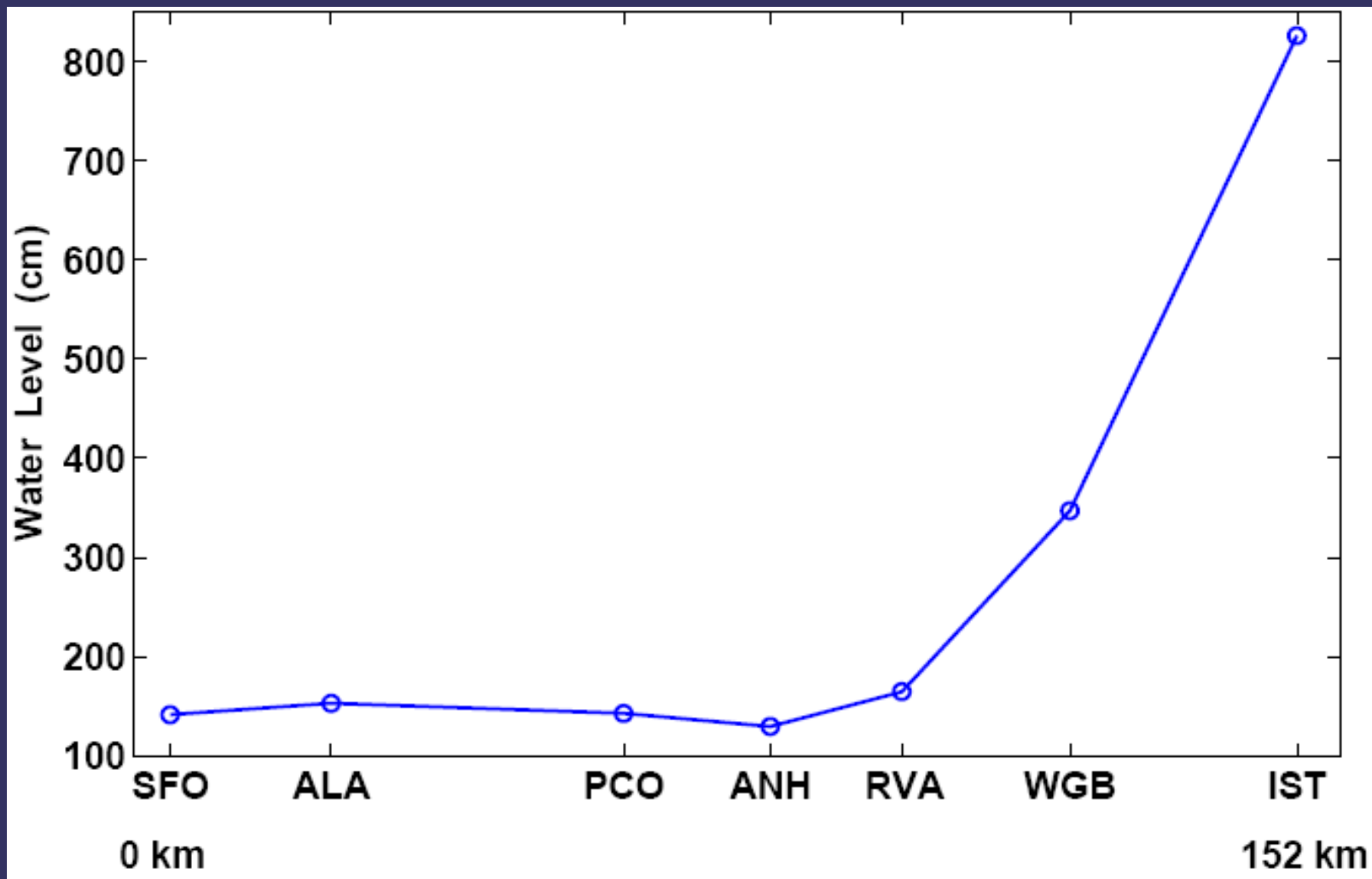
High anomalous sea level in 1998 illustrates that water level anomalies grow larger from San Francisco to Delta-ward locations.



Sacramento River water level is dominated by floods

Sacramento peak flows during the New Years 1997 storm were almost as large as the 1993 Mississippi peak flood flows
 Orographic precipitation in Sierra Nevada:

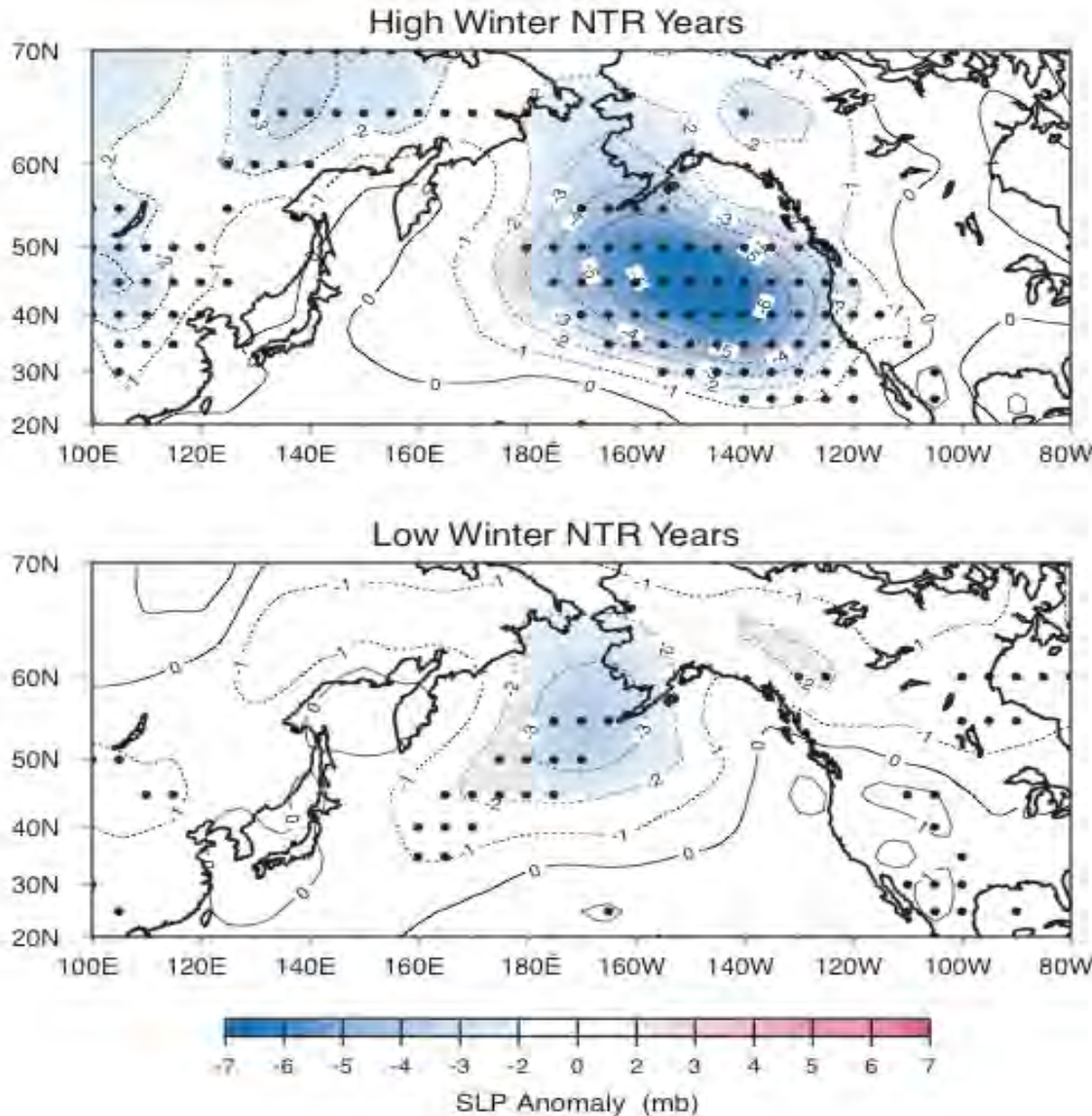
Dettinger, M.D., et al. 2004: Winter orographic-precipitation ratios in the Sierra Nevada – large-scale atmospheric circulations and hydrologic consequences. *J. Hydrometeorology*. **5**(6), 1102–1116.



Extreme water levels from San Francisco to Sacramento

Extreme elevations are the 99.99th percentile levels for 1993-2002, relative to the mean low river flow, from all data within that span (may be different numbers of observations due to different recording gaps). Mean low river flow reference levels were estimated as the mean of the all of the data from the low river flow period during 1991 and 1992.

Monthly Anomalous Atmospheric Circulation Patterns



Intensified, southerly displaced Aleutian Low during the 10 highest non-Tide winter extremes since 1900

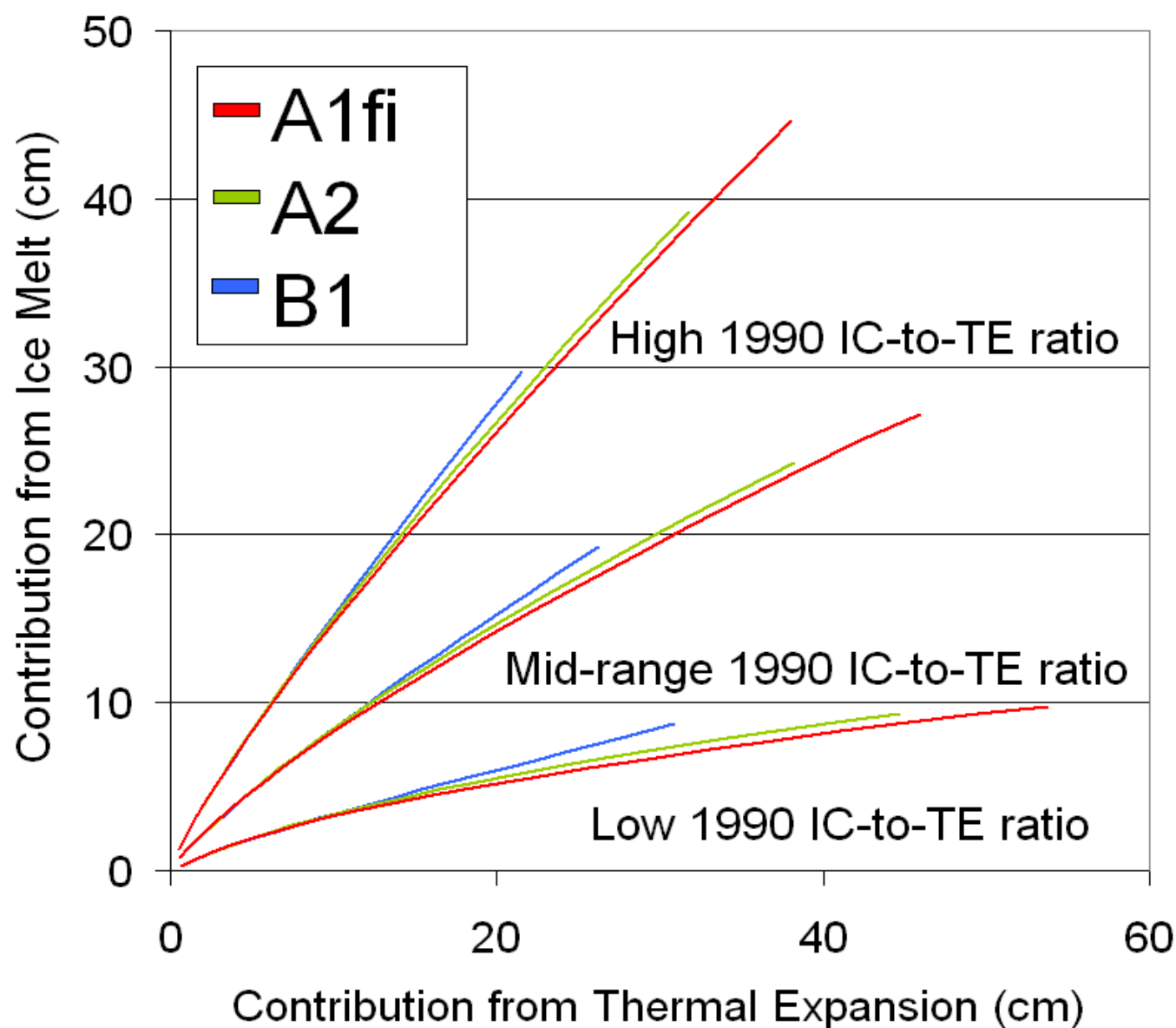
The footprint of low barometric pressure and high winds during these events is often quite large, creating simultaneous Sea level disturbances over the coast, Bay And Delta

GLOBAL “COASTAL” SEA LEVEL RISE

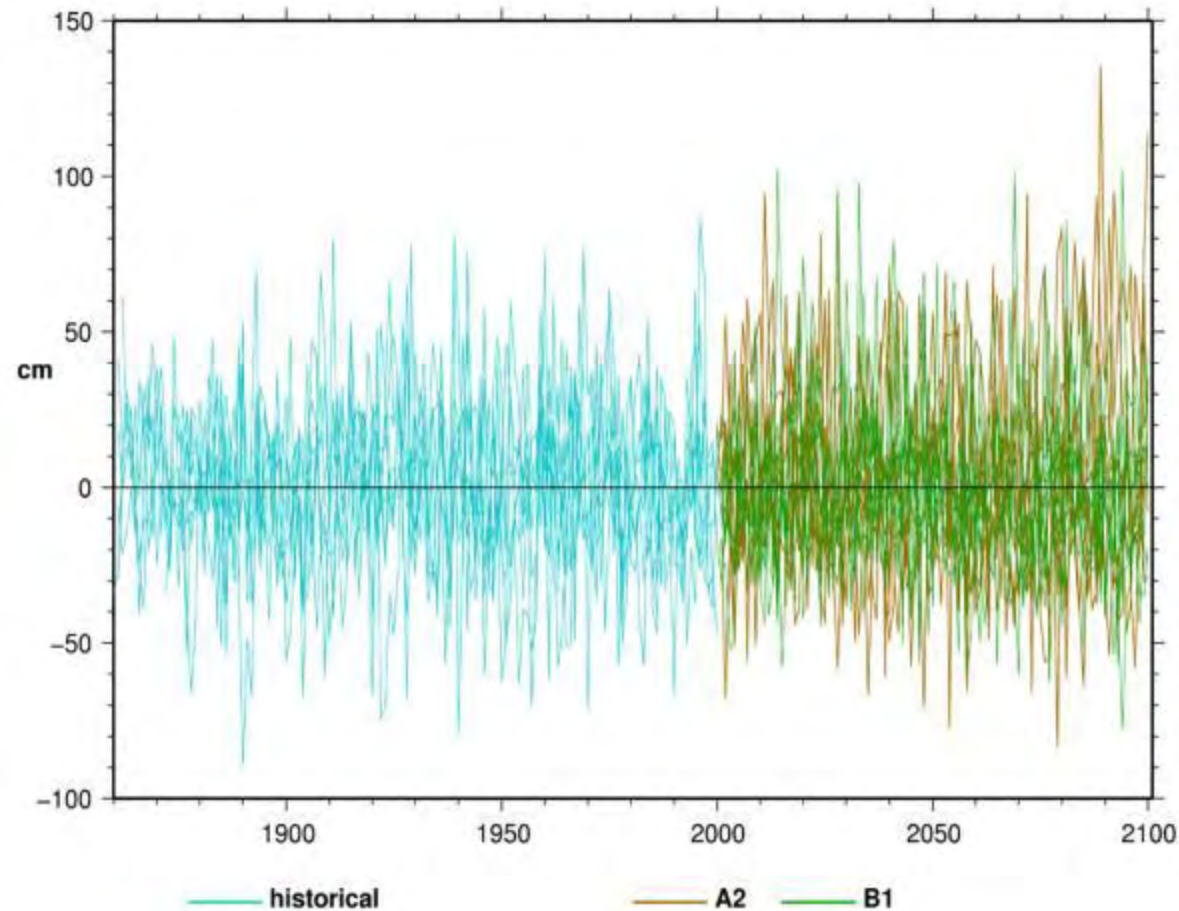
- Steric (thermal expansion from warming of the world's oceans)
~ 3 - 6 cm/century (Levitus et al.)
- Eustatic (added water from melting glaciers and ice caps)
~ 6 cm/century (IPCC)

Global MSL rise: ~ 20 cm / century

Estimates of sea level rise from global change are uncertain, largely because ground-based ice melt is not well understood.



Annual Precipitation Projections, Sacramento area
from 8 IPCC AR4 global climate models, SRES A2, B1

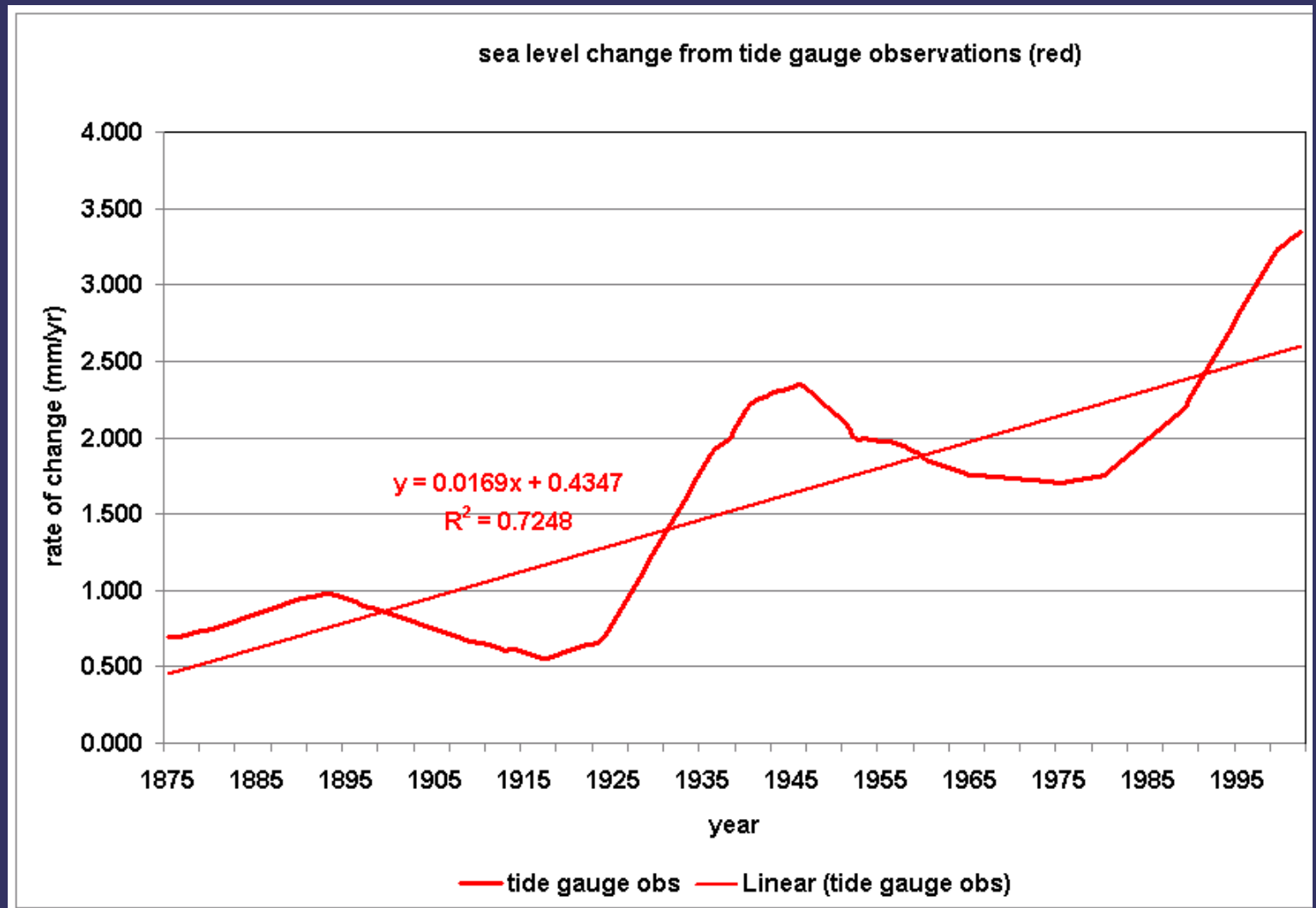


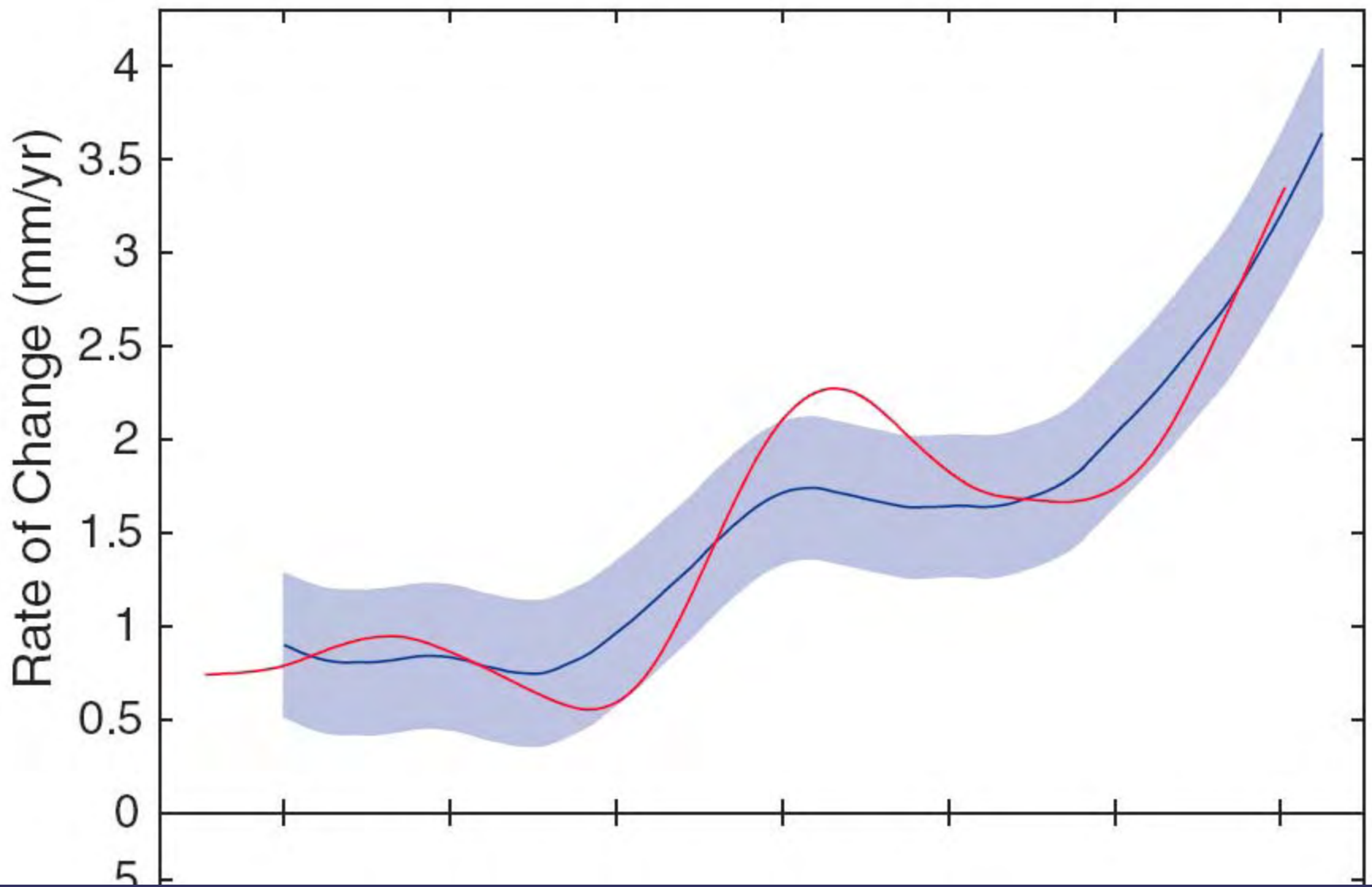
GFDL CM2.1 -- NCAR PCM1 -- MIROC3.2 -- CSIRO Mk3.0
IPSL CM4.0 -- MPI ECHAM5 -- CNRM CM3.0 -- UKMO HadCM3

Uncertain
precipitation changes

But faint trend
toward drying

This is a plot from Microsoft Excel of the values
Jen entered from top of Fig 3 in Rahmstorf paper (next slide)



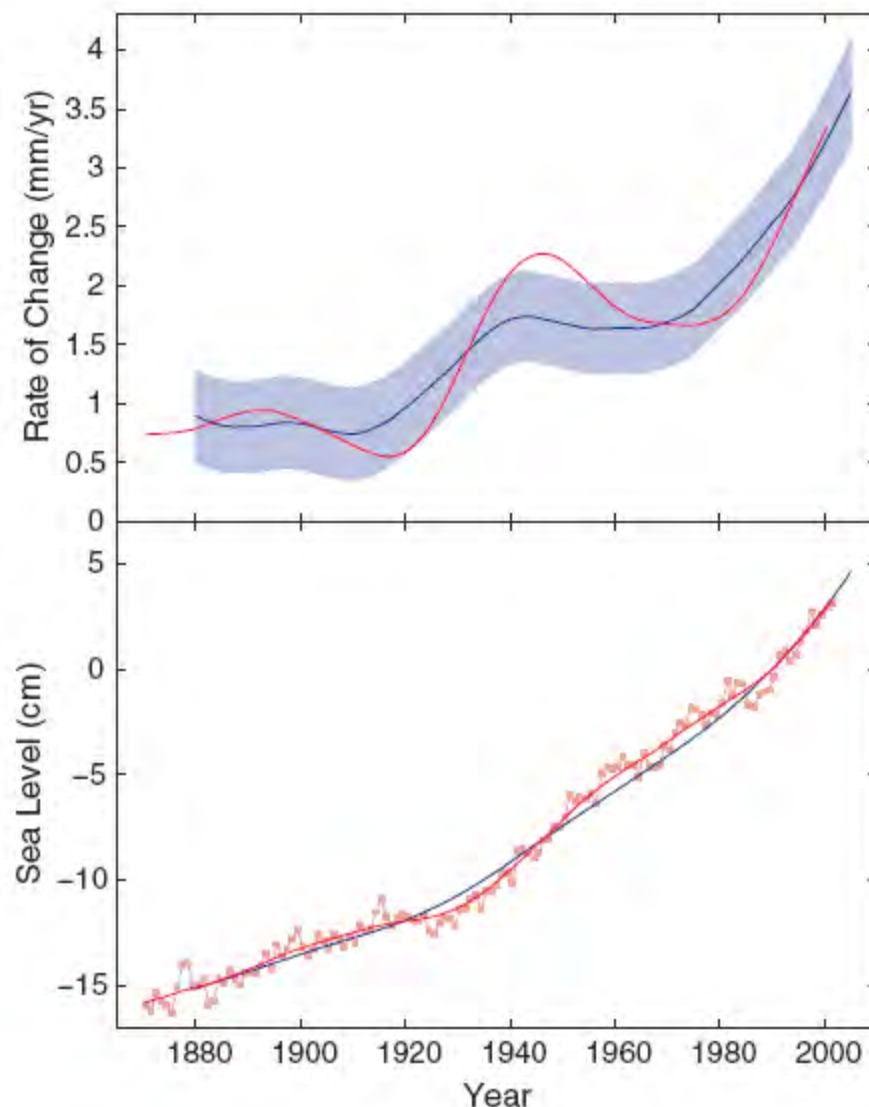


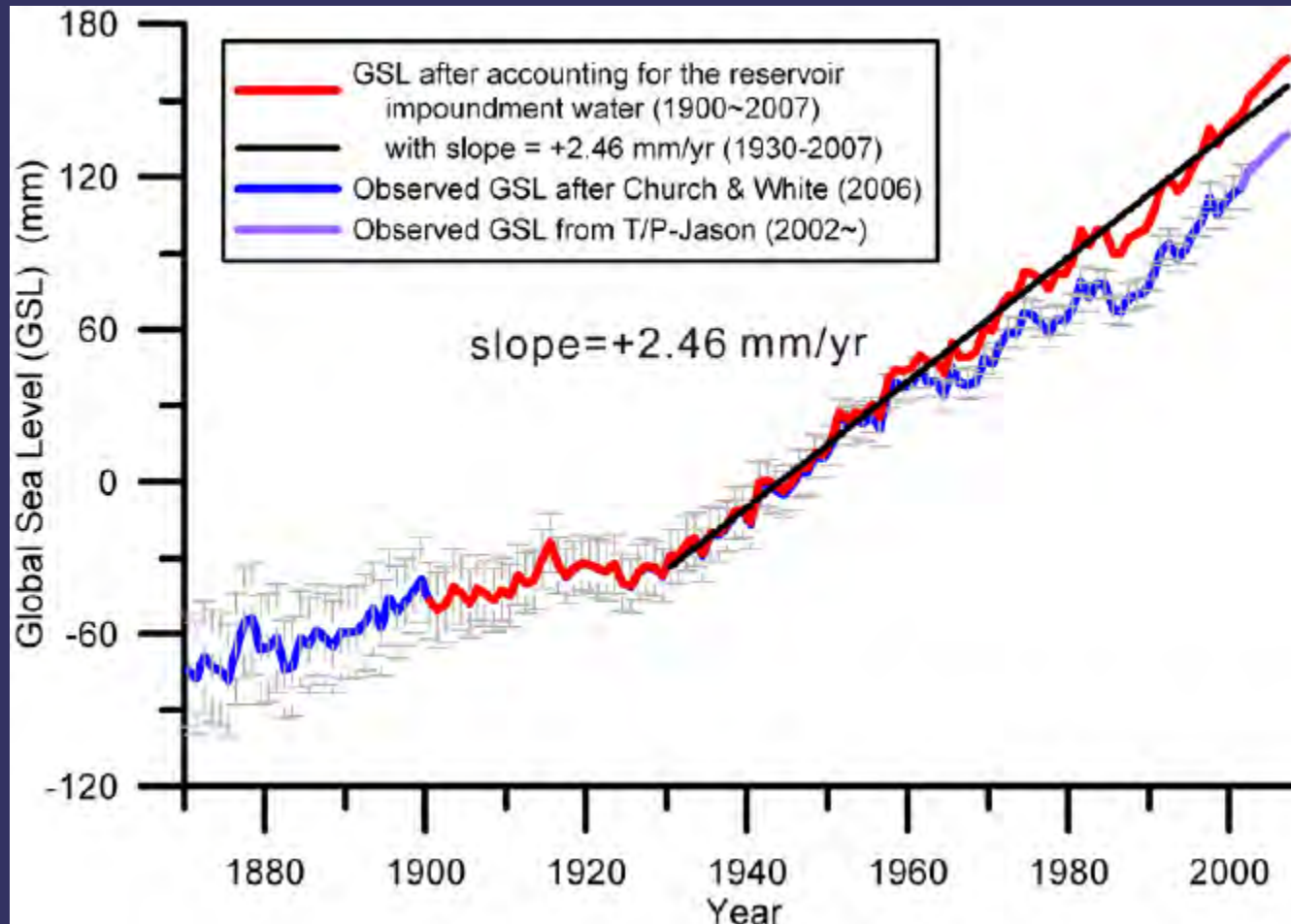
Blow-up of top of figure 3 from Rahmstorf (full fig next slide)

A Semi-Empirical Approach to Projecting Future Sea-Level Rise

Stefan Rahmstorf

Fig. 3. (Top) Rate of sea-level rise obtained from tide gauge observations (red line, smoothed as described in the Fig. 2 legend) and computed from global mean temperature from Eq. 1 (dark blue line). The light blue band indicates the statistical error (one SD) of the simple linear prediction (15). **(Bottom)** Sea level relative to 1990 obtained from observations (red line, smoothed as described in the Fig. 2 legend) and computed from global mean temperature from Eq. 2 (blue line). The red squares mark the unsmoothed, annual sea-level data.





Impact of Artificial Reservoir Water Impoundment on Global Sea Level

B. F. Chao,* Y. H. Wu, Y. S. Li

Climate Scenarios Assessment, California now in its 2nd version:

California politicians have decided to act on climate change. This requires sound science to inform policy that emerges.

GHG emission targets having been set decades in the future, means that we are beset with considerable uncertainty--thus, scenarios of potential future climate changes and impacts are an important planning tool.

Regional specificity of climate change and resulting impacts are required to inform California decision makers. More spatial detail is needed than has been available.

Beyond climate science, there is a broad spectrum of cross- and interdisciplinary study that must be undertaken. Several disciplines are only beginning to learn how to work together.

Many of the hard problems are not well enough understood to afford useful off-the-shelf models, and in many cases necessary observational datasets over reasonably long historical periods have not been collected or processed.